ARCHIVES OF SURGERY

VOL. 5 NOVEMBER, 1922 No. 3

OSTEOSCLEROSIS FRAGILIS GENERALISATA

MARMORKNOCHEN: ALBERS-SCHÖNBERG DISEASE *

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A patient who entered the hospital with a fracture of the right leg, the result of a rather trivial injury, giving a history of previous fractures, likewise following slight trauma, was found, on roentgen-ray examination, to have a pathologic fracture as the result of a rather obscure bone condition which has been termed osteosclerosis fragilis generalisata, Marmorknochen (marble bone), or Albers-Schönberg disease. Inasmuch as only nine other cases of this disease have been reported, all of which have been in the foreign literature, none in the English language, the history of this case is given, together with the roentgen-ray study of the entire skeleton and a review of the literature of this subject to date.

REPORT OF CASE

History.—W. S., a schoolboy, aged 11 years, born in this country, was admitted to my service at the Cook County Hospital, April 20, 1922. He was brought to the hospital by his mother, who stated that, on April 18, 1922, he sustained an injury of the right leg. A playmate who was swinging him around became dizzy and fell with the patient, stepping on his right leg above the ankle. The patient had to be carried home, where he stayed in bed. He entered the hospital because of pain, tenderness and very slight swelling of the lower part of the right leg and inability to use it.

He sustained a fracture of both bones of the left leg in July, 1920, when he fell out of a window, about 4 feet high, striking the middle of the left leg on a step. No physician was called at the time but a firm bandage was applied. He was unable to walk on the leg for three weeks. A fracture of the left femur occurred in November, 1920, when another boy pushed him against a fire hydrant. He was treated in St. Elizabeth's Hospital at that time. The tonsils and adenoids were removed in 1918. He had a mild attack of appendicitis in 1917. He had had pneumonia seven times—at 4 months, 14 months, 3 years, 4 years, 6 years, and 10 years of age. With the last attack, he had an associated otitis media on the right side, at which time an "abscess was lanced." His hearing in the right ear at the time of examination was not so good as in the left.

He was essentially normal. His birth had been normal (a precipitate 10 pound baby). He was breast fed, his feedings being supplemented by cow's

* The author is indebted to Dr. Arthur R. Metz for the roentgenographic examination and the notes on it.

milk after three months and up to sixteen months, when he was taken off both the breast and the bottle. He usually stood high in his school work. He was in the high fifth grade.

His father and mother were both living and well. Two brothers were living and well. One brother had had "heart trouble." One brother died of pneumonia at 16 months. This brother was paralyzed on one side for a month, at 3 months of age.

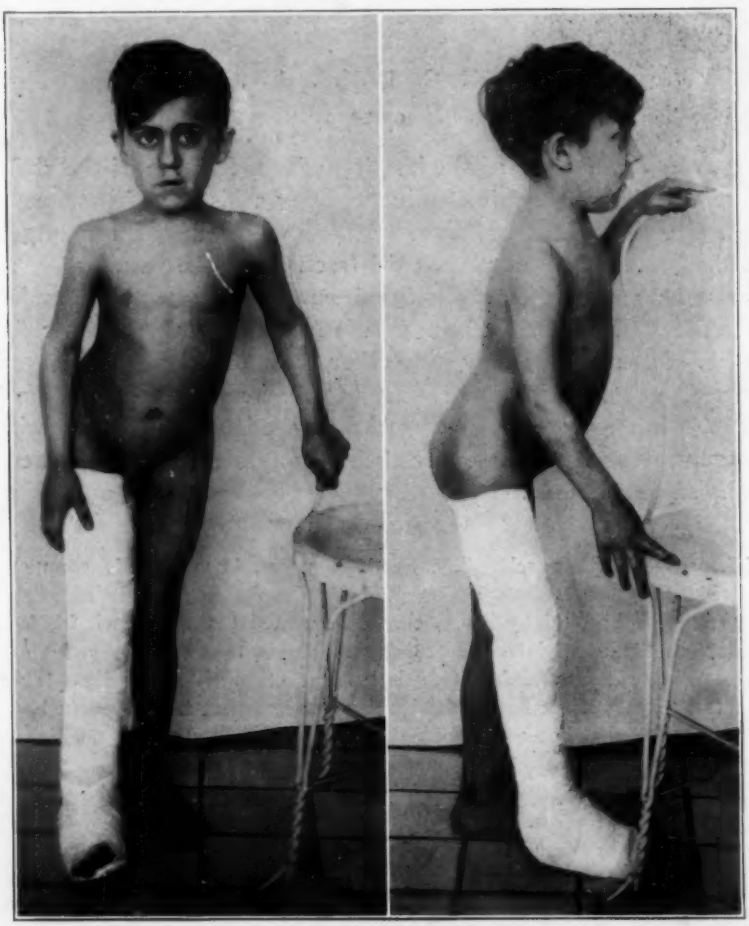

Fig. 1.—Left, anterior view of patient (W. S.), aged 11, with generalized osteosclerosis fragilis; right, lateral view of patient.

Physical Examination.—The patient was fairly well nourished, 3 feet 7½ inches tall (110 cm.) and weighed 49 pounds (22 kg.). There was loss of function of the right leg, with extreme pain and tenderness to touch over the lower third, with slight swelling but no deformity.

His head was large and had a long anteroposterior diameter. His eyes were brown and reacted well to light and on accommodation. The ears were negative externally, but there was an old otitis media on the right side. The septum

of the nose was deflected to the right. Many of the teeth were carious. The tongue was negative and the tonsils had been removed. The hard palate was extremely high. The cervical glands were palpable. The chest was symmetrical, except for a very slight scoliosis to the right in the middorsal region. A very slight suggestion of a Harrison's groove was present. The excursion and expansion of the lungs were good, and there was no area of dulness or râles. The apex beat was within the nipple line, 5 cm. to the left of the median line. There was no enlargement or murmurs. In the abdomen, there were no palpable tumors or areas of tenderness. The limbs were practically negative except for the pathologic condition noted above, and that the radial epiphyses were noticeably enlarged.

Laboratory Findings.—The blood pressure was: systolic, 128, and diastolic, 85. Hemoglobin was 86; erythrocytes, 4,992,000; color index, 86; leukocytes, 11,000. The urinary findings were negative. The specific gravity was 1.014, and the reaction acid. There was no albumin, sugar, acetone, diacetic acid, blood, cells or casts. The spinal fluid was clear and of normal pressure and gave a negative Wassermann reaction. The blood Wassermann reaction was also negative. The blood chemistry was: total nitrogen, 34.30 (normal, 26.50); urea nitrogen, 21.48 (normal, 10); urea, 45.96 (normal, 21.40); uric acid, 1.95 (normal, 1.80); creatinin, 1.54 (normal, 1.35); sugar, 93 (normal, 100).

A blood Wassermann test on the mother gave a negative result.

July 10, 1922, an examination of the basal metabolic rate showed 52.5 calories, which is normal for a boy weighing 46 pounds, 44 inches high and 11 years old.

Roentgen-Ray Examination.—This revealed a fracture of the right tibia at the juncture of the middle and lower thirds, without displacement of fragments, together with other pathologic conditions of the bone. A posterior molded splint was applied and the fracture showed union without much callus, the splint not being removed until June 21, 1922.

Course.—About June 8, 1922, the patient developed severe pain and tenderness over the left scapula, associated later with redness, heat and fluctuation. The white blood count was 27,900; temperature, 99.4 F. Aspiration of pus revealed gram-positive cocci in staphylococcus formation. Cultures of pus revealed hemolytic colonies. Incision revealed a thick yellow pus.

Diagnosis.—Pathologic fracture of the right tibia associated with osteosclerosis fragilis generalisata; old otitis media on the right side; probably old rickets; slight scoliosis of the middorsal spine; periostitis (?) of the left scapula.

Roentgen-Ray Examination.—Roentgenographic examination of the entire skeleton revealed a generalized disturbance of the bony structure, characterized by a marked, irregularly increased density of some portions of the bones, with thinning and rarefaction in other areas. In the long bones, the tendency was toward a marked narrowing of the medullary canals in the middle third, due to a thickening of the cortex, with the ends of the shaft presenting an expanded appearance, with a thinning of the cortex and a coarsely mottled effect due to increased density in the marrow cavity. The small bones, such as the vertebrae, carpals, and tarsals, presented a generalized increased density, with absence of bone structure. The epiphyseal lines were all present and were normal in width, but had slightly irregular margins. There was a general increase of density of the epiphyses, with absence of bony structure, but they appeared normal in size and outline. A detailed description of the bony changes is presented in the six roentgenograms, which altogether include the entire

skeleton; the bones of the hands, forearms and lower humeri are reproduced in Figure 2; feet, Figure 3; femurs and pelvis, Figure 4; legs, Figure 5; trunk, Figure 6; head, Figure 7.

In the examination of the hands, forearms and lower humeri (Fig. 2), the following pathologic findings were noted: The structural contour of the phalanges was preserved, though the phalanges themselves were thickened. The

Fig. 2.—General marble-like picture of the bones of the hands, forearms and arms; transverse, parallel, disklike bands in the phalanges and metacarpals; fracture of the distal epiphysis of left radius.

medullary portion was changed to compact bony tissue at the distal ends of all phalanges. This occurred in such a manner that it left a triangular area of lesser density at the proximal end of each phalanx, with the base of the triangle at the proximal end of each phalanx and the apex pointing toward the distal end. At the apexes of these triangles, small isolated areas of calcification were noted, especially in the proximal phalanges. At the base of these triangles,

parallel, transverse bands of lime deposits were noted. These were especially marked in the thumbs. Parallel hairlike lines also ran from the base of this triangle toward the apex. The proximal ends of the bodies of the phalanges at the base of the triangle described were structureless and of marble-like density, as were also the centers of ossification for the proximal ends of the bone, a well defined line separating the former from the latter.

The metacarpals showed similar changes, the greater portion of the bones presenting a marble-like density. The distal extremities of each of the second, third, fourth and fifth bones, corresponding to the distal center of ossification, showed great density. Similarly, the proximal, or epiphyseal, portion of the

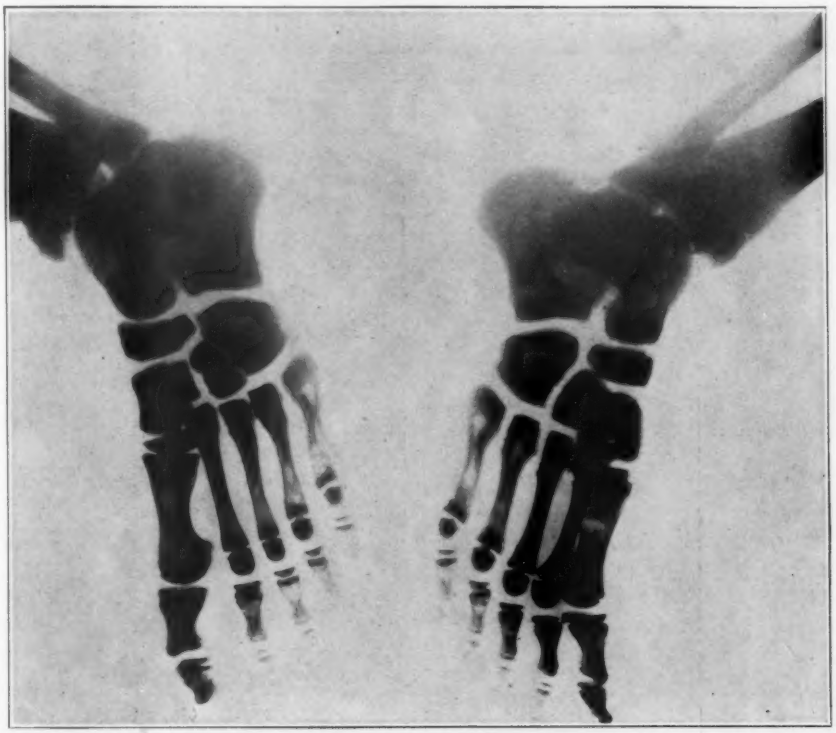

Fig. 3.—General marble-like picture of the bones of the feet; parallel lines of calcification running in superimposed disklike fashion at the base of the first metatarsals; peripheral and central calcification of the cuboid bone, with an area of lesser density between.

first metacarpal showed great density. A triangular area of lesser density, with its base at the distal end of the bodies of the metacarpals, was noted in the metacarpal bones corresponding to the fingers. The base of the triangle of light area in the metacarpal corresponding to the thumb was toward the proximal end of the body of the bone and presented well defined, disklike, parallel, transverse bands of calcification. There was a trace of a distal epiphyseal line in each of the first metacarpals.

The carpal bones presented a compact, structureless mass of marble-like density.

The epiphyses of the radius showed the same marble-like density and a well defined epiphyseal line in the upper portion, not so well defined in the lower. The lower epiphysis of the left radius was definitely shown to be fractured, although the patient made no complaint of this.

The diaphysis of each radius was curved slightly toward the radial side, and was very dense, the medullary canal being almost obliterated in pro-

Fig. 4.—Hour-glass-like narrowing of the medullary canal due to thickening of the cortex in the middle third of the femur, and transverse layers of increased density in the expanded distal portion of the medullary canal; increased density of the pelvis.

portion to the thickening of the corticalis. Each ulna presented a picture similar to that of the radius. There was more or less clubbing of the upper ends of both bones of the forearm. Peri-articular calcification of the elbow joint was noted in the area between the head of the radius and the capitellum. The lower end of each humerus, although preserving its normal contour, showed

the same marble-like density, the medullary canal being very narrow, with a corresponding thickening of the compact substance.

The examination of the feet (Fig. 3) revealed a picture quite similar to that noted in the hands. The disklike, parallel, transverse shadows at the proximal ends of the first metatarsals were particularly well defined. The tarsal bones, with the exception of the cuboid, showed the same compact,

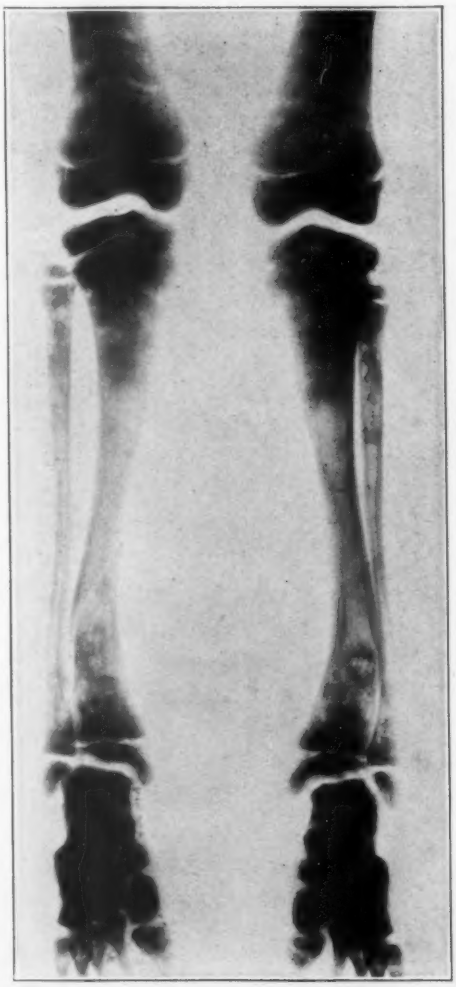

Fig. 5.—Pathologic oblique fracture through the distal third of right tibia; outward bowing of the shafts of the tibia and fibula; increased density of the long bones; marked increase in density of the epiphyses.

structureless, dense, marble-like condition noted in the carpal bones. The cuboid showed a peripheral shadow which, toward the inside, gave place to a lighter area, which again showed a greater density in its center. There was no calcification of the tendon of Achilles at its insertion, as noted by Schulze in his case.

The femurs (Fig. 4) were symmetrically involved, with a marked increased density of the proximal and distal thirds, with an hour-glass-like narrowing of the medullary canal in the middle third, due to a thickening of the cortex. Toward each end, the cortex was gradually thinned and the medullary canal correspondingly expanded. This was most marked in the distal portion. In this expanded medullary canal, there were seven irregular, transverse layers

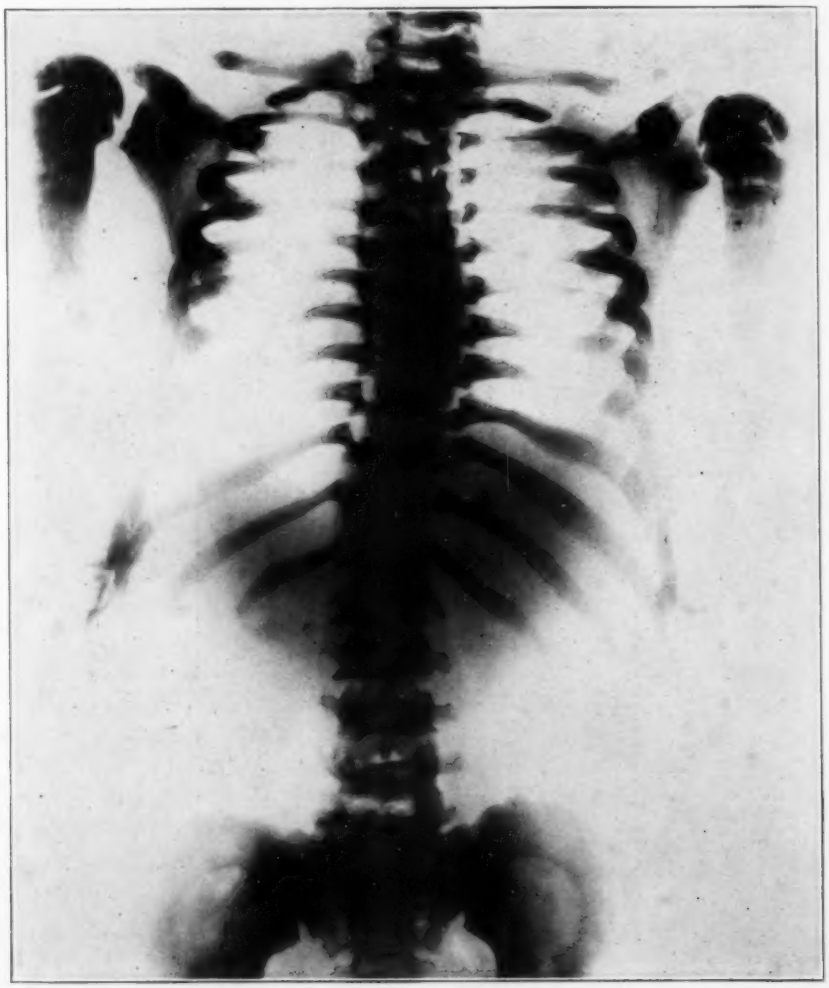

Fig. 6.—Scoliosis of the dorsal spine; ribs larger and denser than normally with the absence of bony structure; increased density of scapulas, most pronounced about the head and coracoid process; humeri similar to femurs.

of increased density, about 1 cm. in width, which may have represented periods of growth. There was an absence of normal bone structure. The epiphyseal lines appeared normal. The distal epiphyses were markedly increased in density, with absence of bone structure. The proximal third presented a more uniformly increased density than the distal, with absence of the transverse layer formation, and a less marked thinning of the cortex. The epiphyses of

the head and great trochanter presented the marked dense appearance, with absence of bony structure. There was no bowing or evidence of injury and the margins were smooth in outline.

The pelvis was normal in size and shape, presenting a marked increase in density. The margin of the crests of the ilia was irregular in outline. In the central portion of each wing, there was a circular area, 3 cm. in diameter, which was less dense and appeared like normal bone about which were concentric layers of increased density which suggested periods of growth.

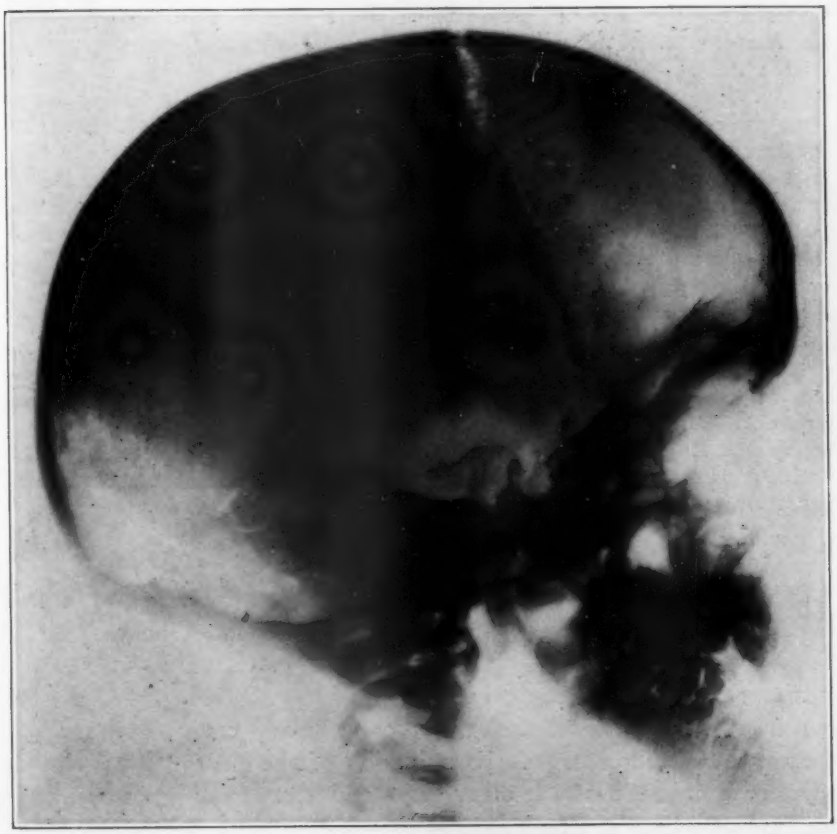

Fig. 7.—Skull showing a definite increase in density about the base of the middle and frontal fossae; posterior and anterior clinoid processes enlarged, increased in density; the posterior, a clublike prominence.

The tibias (Fig. 5) were similar in appearance, except for an oblique fracture extending for a distance of 8 cm. through the distal third of the right. The fragments were in good position and there was evidence of callus formation. There was definite bowing outward of the shaft. The middle third was similar in appearance to the femurs. The proximal third presented a similar appearance to that of the distal third of the femur, having the indistinct transverse layers of increased density, of which five could be identified. In

the distal third, the density was irregular and presented no suggestion of layer formation. The epiphyses were markedly increased in density, with absence of bony structure.

The fibulas presented the same general characteristics as the femurs and tibias. There was a slight scoliosis of the spine (Fig. 6), and the bodies of all the vertebrae showed a marked increase in density. The ribs were larger and denser than normal, with absence of bony structure. There were the same general changes in the clavicles that were common to the other long bones. The scapulae showed increased density, which was most pronounced about the head and coracoid process. The humeri were symmetrically involved, the proximal two-thirds having an appearance similar to that of the distal portion of the femur, while the distal third showed less change.

The skull (Fig. 7) showed a definite increase in density about the base of the middle and anterior fossae. The anterior and posterior clinoid processes were larger and more dense than normally, the posterior appearing as a clublike bony prominence. The fossa for the pituitary gland was 8 mm. in diameter. The area of the sphenoidal sinus showed a uniformly increased density, leaving no evidence of a cavity. The mastoid areas were similar in appearance, with an increased density and no evidence of mastoid cells. The coronal and lamboid structures were very distinct and appeared normal, as did also the grooves of the meningeal arteries. The vault appeared normal, having a good bony structure, and it was the only part of the skeleton that did appear normal.

These changes showed that there had been a generalized disturbance in the bone forming elements, in which there was an increased bone production, together with a thinning out of the structure in other parts, leaving the bone rather fragile, as is demonstrated by the oblique fracture of the right tibia, which was the result of a very minor injury. If the layer formations which could be demonstrated are interpreted as periods of growth, each of a year's duration, we may conclude that the process had been going on for about seven years.

LITERATURE

In 1904, Albers-Schönberg [1] presented roentgenograms of a rare bone disease which hitherto had been undescribed. A man, aged 26, fell into a shallow rut and fractured the femur. Roentgen-ray examination revealed that the bony structure was not recognizable. The bones gave deep, black shadows; the medullary cavity was lacking; the corticalis was diffused. Examination of the entire bony structure revealed a fracture of the other thigh and one of the olecranon. Of the origin of these the patient knew nothing.

Besides the deep, dark bone shadows, there were several transverse rings visible on the shorter bones of the extremities, as well as on the ribs. The whole picture suggested an unusually pronounced calcification of the whole skeleton.

In 1907, Albers-Schönberg [2] enlarged on the earlier report (1904) of his patient, who now enjoyed perfect health, and worked as a

1. Albers-Schönberg: Röntgenbilder einer seltenen Knochenerkrankung, München. med Wchnschr. **51**:365, 1904.

2. Albers-Schönberg: Eine bisher nicht beschriebene Allgemeinerkrankung des Skeletts im Röntgenbilde, Fortschr. a. d. Geb. d. Röntgenstrahlen **11**:261, 1907.

merchant without any trouble. Symptoms given in the first description were still unchanged. He adds the picture of the condition of the skull, which is peculiar in the region of the sella turcica. The posterior clinoid process consisted of a club-shaped solid bony prominence, which apparently indented the region of the sella. The crista galli also showed the same changes. The other bones showed a marble-like character.

In conclusion, Albers-Schönberg emphasized besides the marble-like changes of the bones, the especially characteristic appearance of parallel bands of lime in the diaphyses of the bones of the hand, of the feet, of the fibula and on the ribs. He emphasized the fact that these were the result of especially dense lime deposits. The etiology of this condition is not known.

In 1913, Schmidt [3] reported a case. He wished to introduce the name of "lime gout" because of the similarity between the process in extensive lime deposit due to metabolic disturbances, and the genuine uric acid gout.

The case reported by Schmidt was that of congenital osteosclerosis, in which the long pipe bones were less affected than the vertebrae, the base of the skull and the sternum. The child was well developed, and died thirty hours after birth. The blood was that of a normal cadaver. The bone marrow showed a physiologic cell synthesis without signs of a fibrous change or a leukemic or pseudoleukemic disease. There was also enlargement of the hypophysis.

In 1914, Sieck [4] reported three cases of a rare disease of the skeleton.

CASE 1.—A girl, aged 15, undeveloped for her years, had been apparently well in early youth. Her growth was impeded when 5 years old by a slight fracture of the femur. In the course of the years, she had fourteen other fractures. There was gradual increase in defect of eye-sight. During the last two years, suppuration of the lower jaw had occurred, causing almost all the teeth to fall out. Ophthalmoscopically, considerable optic nerve atrophy was revealed. Roentgen-ray examination revealed complete, structureless skull bones. The sella turcica was narrowed. The clinoid process projected greatly. The femur, tibia and fibula of both sides showed club-shaped thickenings. In the lower half of the tibia, parallel to the middle of the diaphyses, were convex streaks. The epiphyses, as well as the diaphyses, were without structure and only in the lower third of the leg (below the knee) could the corticalis and medullary space still be distinguished. In the upper extremities were different, deformed, healed fractures. The upper half of the humerus was thickened like a club, and the lower half showed transverse striations, like the tibia, with the concavities toward the diaphyses.

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3. Schmidt, M. B.: Kalkmetastase und Kalkgicht, Deutsch. med. Wchnschr. **39**:59, 1913.

4. Sieck: Ueber drei Fälle einer seltenen Skeletterkrankung (Marmorknochen nach Albers-Schönberg), Festschrift zur Feier des 25 jährigen Bestehens des Eppendorfer Krankenhauses, 1914.

Case 2.—A boy, aged 3½ years, with hydrocephalus, great decrease in vision, and beginning optic nerve atrophy, presented a perceptibly enlarged posterior clinoid process. The base of the skull and the skeleton of the face were thickened and structureless. The humerus in its upper end was club-shaped. The metacarpals and phalanges were thickened. The talus, calcaneus and cuboid showed, in the roentgenogram, a peripheral shadow which, toward the inside, gave place to a lighter area so as to show again a thickening in the center.

Case 3.—A girl, aged 2½ years, with hydrocephalus and optic nerve atrophy, presented a narrowed sella turcica, but not so pronounced as in Case 2. The posterior clinoid process, however, was plainly enlarged. The bones of the skull and extremities were of the same structureless nature as in the preceding case. This patient and the patient in Case 2 were brother and sister.

Sieck believes that the fine parallel streaks in the diaphyses are zones of growth.

In 1915, Reiche [5] described a case of osteosclerosis and anemia.

The patient was a man, 37 years old, mentally active. He was delicately built and looked pale. He was married and had no children. He had an excessive appetite, and required a great deal of sleep. Roentgenograms revealed thickening of the bones. In the left groin was a tumor the size of a child's fist, which was sensitive to pressure. The liver projected about one and one-half finger breaths over the right costal arch.

The condition of the blood was as follows: The hemoglobin content was permanently decreased and varied between 30 and 36. Microscopically, the red blood corpuscles varied greatly in size. Erythrocytes were seen in some of the preparations. Blood platelets were present in abundance. The number of polymorphonuclear leukocytes was permanently decreased, which multiplied the number of lymphocytes.

Reiche concludes that no peculiarity in the blood picture exists in cases of osteosclerotic anemia, and that so far roentgenography is the best procedure to determine the characteristic marble-like density of the bones.

In 1917, Pick [6] called attention to the fact that it could not be proved macroscopically that the changes in the bone were responsible for the appearance of the lime deposits, and that they reminded one of the picture of classical lime metabolism. Schulze [7] found double the normal lime value of the blood in his case; and, in considering the progressive exhaustion of the bone substance and the enrichment of the blood with lime salts, he suggests that this follows a low grade of activity of the osteoblasts, and the lime is incompletely utilized in forming new bone substance.

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5. Reiche, F.: Osteosklerose und Anämie, München. med. Wchnschr. **62**: 944 (July 13) 1915.

6. Pick, L: Die indikatorische Bedeutung der Kalkmetastase für den Knochenabbau, Berlin klin. Wchnschr. **54**:797, 1917.

7. Schulze, Fritz: Das Wesen des Krankheitsbildes der "Marmorknochen (Albers-Schönberg)," Arch. f. klin. Chir. **118**:411, 1921.

In 1920 Laurell and Wallgren [8] described a disease of the skeleton originally observed in a boy of 12. The skeleton showed general fragility, with a marble-like appearance.

Ernst E., aged 12 years, was the third of five children. The other children were healthy, without any sign of rickets or other bone disease. The family history was negative. At one-half year, he had not developed much since birth. He was pale and irritable and cried all day long. The head seemed to grow, although the body did not. Up to the age of 5 or 6 years, the skull circumference increased very noticeably. At about 1 year of age, his mother noticed that he had nystagmus. After his second year, it was discovered that his vision was defective. At 2½ years he could walk and talk quite well. At the age of 1 year his first teeth appeared, and the rest came in slowly and irregularly. At 3 years of age, his parents consulted a physician who diagnosed his case as rickets and hydrocephalus and prescribed cod liver oil. No great improvement followed. In 1915, when the boy was 8 years old, he fell backward down the stairs and fractured the right femur, for which he was treated for eight weeks at the hospital and was then discharged with good callus formation. The next year he broke his left leg. This fracture also healed. In the following year he suffered still another fracture of the left leg. In 1918, the right femur was fractured; this healed after six weeks. In July, 1919, without known injury or accident, the right femur was again fractured. He was sent to the hospital, the fracture healed, and he was then transferred to the children's ward.

Roentgen-ray examination revealed old fractures in other parts of the skeleton. On admission, the boy seemed in good general condition, with poor musculature. He was 122 cm. tall and weighed 23.3 kg. He was afebrile; the pulse was 100. His head was large in proportion to the rest of his body. It measured 57.5 cm. in circumference. When he looked to the side, a slow nystagmus was present. When he looked toward the left, this was especially marked. The pupils were wide and reacted normally to light. Vision was limited. There was a bilateral choked disk in the atrophic state, moderate bilateral rhinitis, poor teeth and stomatitis. The tonsils were small and smooth. There was marked lordosis of the lumbar spinal column when he stood. The thorax was deformed, with a deep depression along the insertion of the diaphragm, and a corresponding bulging forward of the edges of the thorax. The abdomen was slightly distended but not painful. The skin and tendon reflexes were active. The Babinski sign on the right was negative; on the left, uncertain. The lungs were normal except for a slight basal bronchitis. The heart sounds were distinct. The blood pressure was 100. The spleen was palpable. The liver was not enlarged. The sexual organs were normal. The Wassermann reaction was negative; the Ross-Jones reaction was negative. Detailed roentgen-ray findings are given.

Examination revealed the fact that the thyroid was nonpalpable. All osseous structures showed an enormous deposition of lime, especially in the cranium and trunk. There was a history of hydrocephalus. The long bones showed condensed lime rings and lateral bands. Experiments were made with the view of determining a possible retention of lime, but the result was nega-

8. Laurell and Wallgren: Untersuchungen über einen Fall einer eigenartigen Skeletterkrankung (Osteosclerosis fragilis generalisata), Upsala Läkaref. Förh. **25**:309 (Nov. 8) 1920.

tive. The diagnosis, founded on history and feeding experiments, was: initial rachitis, complicated by hydrocephalus and a fundamental disturbance of the glands of internal secretion: thyroid, hypophysis and perhaps others, resulting in lime condensation, and some secondary symptoms (serous meningitis, atrophy of the optic nerve, anemia).

Four similar cases are known. Eight roentgenograms show the pathologic structure.

In 1921, Schultz [7] discussed the nature of the disease of marble bones (Albers-Schönberg) and reported a case.

Hugh S., aged 11 years, of healthy family, mentally well developed, had always been well. In 1914 he had scarlet fever. Ever since that time he had been sickly. He was sent to the hospital for disease of the lungs. There was no improvement. There was slowly increasing stiffness of the vertebral column and visible emaciation.

At the time of examination the vertebral column showed a right scoliosis of the upper thoracic vertebrae. The patient was confined to bed. The teeth were decidedly rachitic. Calcification of the ligament of the patella and the Achilles tendon at insertion showed in the roentgenograms, also calcification of the posterior longitudinal ligament of the vertebral column and the plantar ligament was noted.

The ossification of the vessels appeared as a secondary condition, compared with the changes in the entire skeleton. With the exception of the metaphyseal regions, the corticalis and medullary space had disappeared in all the long pipe bones. The bones were changed into a compact, structureless, bony mass. These changes also appeared in the short bones, such as the vertebrae and bones of the feet. The axes of the femur, fibula, tibia and forearms showed indistinct curvature. The head of the humerus showed club-shaped thickenings. The head of the left femur stood in coxa-valga position.

Necropsy revealed that the degree of thickness of the bone substance was increased, inasmuch as there were lime deposits in the marrow spaces, which in places completely filled the marrow space, with the exception of very small blood vessel canaliculi. This lime deposit rested partly on the wall of the arteries but was independent of the condition of the medullary tissue. Bone changes were found in the whole skeleton. The posterior clinoid process and the sella turcica showed clublike thickenings, which authorities believe cause a decrease in function of the hypophysis.

Worthy of notice was the considerable narrowness of all the foramina of the base of the skull. This narrowing seemed to justify the conclusion that the optic nerve atrophy, which is so often noticed, might be due to bony pressure upon the optic nerve. Schulze believes that the slow bone formation is responsible for the increase in the lime content in the blood and can be considered as a final result of defects in the lime metabolism.

In this disease, according to Virchow,[9] the normal excretion of lime

9. Virchow: Die Kalkmetastase, Virchows Arch. f. path. Anat. **81**:618, 1856; ibid. **81**:103, 1855.

salts is reduced because of inflamed or diseased kidneys, an accumulation of these salts in the blood occurring as a consequence. It has been shown, however, that marked disturbances in lime metabolism are possible even when the kidneys are not diseased. The kidneys in the case observed by Virchow presented a hyaline degeneration of the glomeruli due to an obliterating endarteritis and calcification. The process which at first seemed dependent on an excess of lime salts in the blood caused extensive calcification of the vessels.

According to Reiche, the osteosclerosis in his case was caused by myelogenous leukemia or pseudoleukemia, but this is not very probable. On the contrary, there exists a similarity between this condition and rachitis, as is shown by the condition of the proliferative cartilage zone.

Microscopically, the formation of the periosteal new bone is very slight. The bone very often appears to be incomplete because of the imperfect bone corpuscles. The cambium layer of the periosteum is distinctly recognizable, but shows flat, spindle-like cells, without any very active zones of proliferation.

According to Lorey,[10] cited by Schulze, the three children reported by Sieck died with symptoms of anemia due to maxillary necrosis, with protracted suppuration. Lorey reports the findings in a brother of the girls in whom he could observe great thickening of the skeletal system, so that no separation between corticalis and spongiosa was possible.

Especially noticeable was the even thickening of the calcaneus and talus, which did not show a light place in the center, as in the two sisters. The streaks running transversely, which in the other cases were very plain, were not visible in this case. There was increased intraspinal pressure, and optic atrophy in a few weeks caused blindness. The child died at the age of 5 months, after a severe anemia and necrosis of the maxilla with suppuration. Necropsy was not performed.

10. Lorey: Ueber eine sehr seltene Allgemeinerkrunkung des Skeletts (Marmorskelett), Verhandl. der deutsch. Röntgen-Gesellsch., cited by Schulze: Arch. f. klin. Chir. **118**:413, 1921.

OSTEOPSATHYROSIS: REPORT OF A CASE

WITH ROENTGENOGRAMS OF ELEVEN DIFFERENT FRACTURES IN THE SAME PATIENT *

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The accompanying case of osteopsathyrosis was treated and studied in the surgical outpatient department of the Children's Hospital, Boston. The accompanying series of roentgenograms gives a graphic fracture history of the patient from the time he was 9 months old until his death, at 7½ years.

In spite of the large number of cases reported in the literature, osteopsathyrosis, or fragilitas ossium, is a relatively uncommon cause of pathologic fractures. Griffith [1] and Ostheimer [2] had collected 193 cases in all up to 1913, and since then a few cases have been reported. In 1913 one case was reported by Schwarz and Bass,[3] and another by Bamberg and Huldschinsky.[4] In 1914 Bookman [5] reported one, and the following year Kienböck [6] collected thirty-seven cases from the literature (from 1888 to 1914) and added two cases of his own. Blaine [7] reported one case in 1916, and, in 1917, Hess [8] presented four cases and Mixsell [9] two. In 1920 Ruggeri [10] reported one, and in 1921 Vander

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* From the surgical service of the Children's Hospital, Boston, under the direction of Dr. James S. Stone. The roentgenogram reproduced in Figure 12 is used through the courtesy of the Massachusetts General Hospital.

1. Griffith, J. P. C.: The Diseases of Infants and Children, Philadelphia, W. B. Saunders Company **2**:432, 1919.

2. Ostheimer, Maurice: Fragilitas Ossium, J. A. M. A. **63**:1996 (Dec. 5) 1914.

3. Schwarz, Herman, and Bass, M. H.: Osteogenesis Imperfecta: Report of a Case with Study of Its Metabolism, Am. J. Dis. Child. **5**:131 (Feb.) 1913.

4. Bamberg, K., and Huldschinsky, K.: Ueber angeborene Knochenbrüchigkeit, Jahrb. f. Kinderh. **78**:214, 1913.

5. Bookman, A.: The Metabolism in Osteogenesis Imperfecta with Special Reference to Calcium, Am. J. Dis. Child. **7**:436 (June) 1914.

6. Kienböck, R.: Ueber infantile Osteopsathyrose, Fortsch. a. d. Geb. d. Röntgenstrahlen, Hamb. **23**:122, 1915.

7. Blaine, E. S.: Idiopathic Infantile Osteopsathyrosis, Am. J. Roentgenol. **3**:438 (Sept.) 1916.

8. Hess, J. H.: Osteogenesis Imperfecta, Arch.Int. Med. **19**:163 (Feb.) 1917.

9. Mixsell, H. R.: Osteogenesis Imperfecta with Report of Two Cases, Arch. Pediat. **34**:756 (Oct.) 1917.

10. Ruggeri, E.: Idiopathic Osteopsathyrosis, Pediatria **28**:953 (Oct. 15) 1920.

Veer and Dickinson [11] reported one. There have doubtless been others that I have overlooked. In other words, more than 200 cases of osteopsathyrosis have been reported. Contrasted with this apparently large group, we find that in a series of 45,000 births in the Göttingen Frauenclinic, Birnbaum [12] found only one case of fragilitas ossium. Again, in a series of 1,610 long bone fractures (including the clavicle) treated at the Massachusetts General Hospital, only two fractures due to fragilitas ossium are recorded.[13]

REPORT OF CASE

History.—The family history was of no significance. The father, mother and five other children were living and well. There was no history of bone disease, fractures or blue sclerae anywhere in the family. The patient was a full term baby and was delivered normally. He was breast fed for fourteen months. He had had measles, but no other illnesses, except for the fractures he had sustained. His lower, central incisor teeth were present at birth. About a year ago they had come out, and none had replaced them.

When 9 months old, the patient fell, fracturing the left femur just above the condyles (Fig. 1). A plaster spica was applied in the surgical outpatient department of the Children's Hospital, and union resulted, with practically no deformity.

When 21 months old, he was jumping on the porch steps, when he began to cry and to hold up his right leg. He did not fall, but he would not use his right leg after that. The roentgen ray revealed a fracture at about the junction between the upper and middle thirds of the right femur, with slight anterior bowing (Fig. 2). He was admitted to the hospital, where a plaster spica was applied with a pad over the site of the deformity. At that time both femurs showed some anterior bowing, which Dr. James S. Stone then attributed to rickets (Fig. 3). A small cystic rarefaction was noted at the lower end of the left femur.

Soon after discharge from the house, in the following month, the roentgen ray revealed shadows about the site of the fracture, which were rather more extensive than might be expected from callus formation alone (Fig. 4 *A*). Three months later he was again admitted because of a definite tumor mass that had formed at the point of fracture. Because of the possibility of new growth, the tumor mass was excised. Pathologic examination, however, demonstrated the specimen to be callus and not new growth (Fig. 4 *B*). At about this time, the patient complained of inability to flex the right forearm, but there were no clinical signs of fracture. No roentgen-ray examination was made. After immobilizing the arm with an internal angular splint for a few days, all symptoms disappeared.

When 2 years and 9 months old, the patient complained of some pain in the left thigh. The roentgen ray disclosed slight raising of the periosteum along the middle third of the left femur (Fig. 5). A plaster spica was applied and kept on for two months, after which time all symptoms abated.

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11. Vander Veer, E. A., and Dickinson, A. M.: Fragilitas Ossium, Ann. Surg. **74**:629 (Nov.) 1921.

12. Birnbaum, R.: A Clinical Manual of the Malformations and Congenital Diseases of the Foetus, Philadelphia, P. Blakiston's Son & Co., 1912, p. 246.

13. MacDonald, R. F.: Unpublished series of pathologic fractures.

When 3 years old, he fell to the floor from a standing position. His left arm swelled considerably; but the swelling disappeared within a few days, and the function seemed practically normal again. A roentgenogram, taken one week later, revealed a fracture of the left radius, with some lateral displacement, but no overriding (Fig. 6.). Good union was obtained with antero posterior splints.

When he was 4 years old, he fell again, and a green-stick fracture of the left radius resulted (Fig. 7). This fracture united quickly without deformity, after splinting.

Fig. 1.—Fracture of the distal end of the left femur at 9 months (the patient's first fracture).

At 4 years and 5 months, he fell from the davenport, alighting on his right arm. The upper third of the right humerus was fractured with comparatively little displacement (Fig. 8). Good union was obtained by means of a traction splint, after a triangle in the axilla had failed.

When nearly 5 years old, the boy fell from a cart onto his right shoulder, fracturing the right clavicle about the middle (Fig. 9). This break united without deformity, a Velpeau bandage being used. At the same time, roentgeno-

grams were made of both tibias, because of the bowing they presented (Fig. 10). This bowing was interpreted by Dr. Percy Brown as being due to rickets.

When he was nearly 7, the patient fell on the left arm, breaking both bones of the forearm (Fig. 11). He was treated in the outpatient department of the Massachusetts General Hospital, and good union was obtained, although marked bowing of both bones remained.

At 7 years and 3 months, he fell over backward, his weight falling on his hyperextended palms. Swelling appeared over the flexor tendons of the left wrist, and flexion and extension became painful. The swelling and tenderness

Fig. 2.—Fracture of the right femur at 1 year and 9 months.

disappeared in two or three days, but some ecchymosis remained. Slight mobility was detected on palpation, and the roentgen ray demonstrated that a small crack had been opened up at the site of the last radial fracture (Fig. 12). This injury was treated with a posterior splint and pads and adhesive straps to correct the bowing, with fairly good results. Roentgenograms of all the long bones, the skull and the chest were taken at the same time (Figs. 13, 14, 15, 16 and 17). The long bones of the extremities all showed anterolateral

bowing, with marked thickening of the cortex of the diaphysis and relative thinning at the epiphysis. The chest showed nothing remarkable, and the skull showed only moderate thinning.

At 7½ years, the patient tripped over a rug and fell on his right arm. The roentgen ray revealed no evidence of fracture. Nine days later he again fell on the floor at home, breaking the right humerus at about the junction of the middle and upper thirds. The roentgen ray disclosed a clean, right-angled break, with practically no displacement (Fig. 18). He walked into the outpatient department that morning. The arm was immobilized with coaptation

Fig. 3.—Appearance of the left femur at the time of fracture of the right femur, shown in Figure 2. A cystic area is seen in the lower third.

and an internal angular splint. He was kept under observation until late in the afternoon, and, as there was no evidence of other injury, he was allowed to go home. During the evening he vomited several times and was seen by his local physician, who made a diagnosis of fractured skull, sending him to the hospital. On the way to the hospital, he is said to have died from intracranial hemorrhage. Necropsy was not performed.

Physical Examination.—At no time did examination reveal anything remarkable about the patient except bowing of the extremities and slight deformities due to the various fractures. As shown in Figure 19, the boy was well proportioned and of about normal size, with a slightly flattened chest and a rather

prominent abdomen. All of the extremities showed moderate outward bowing. The lower, central incisor teeth were absent, and the alveolar process was much thinned out at that point. There was no evidence of the presence of permanent incisors in the alveolar process to replace the missing teeth. The sclerae were of normal color and did not show the dark bluish tint which has often been described in patients with osteopsathyrosis.

Summary.—The patient was a boy, aged 7½ years, with negative family history, who had sustained multiple long bone fractures, and who died following what was probably a fractured skull. Eleven fractures were demonstrated by the roentgen ray, and there were two other probable fractures which were not

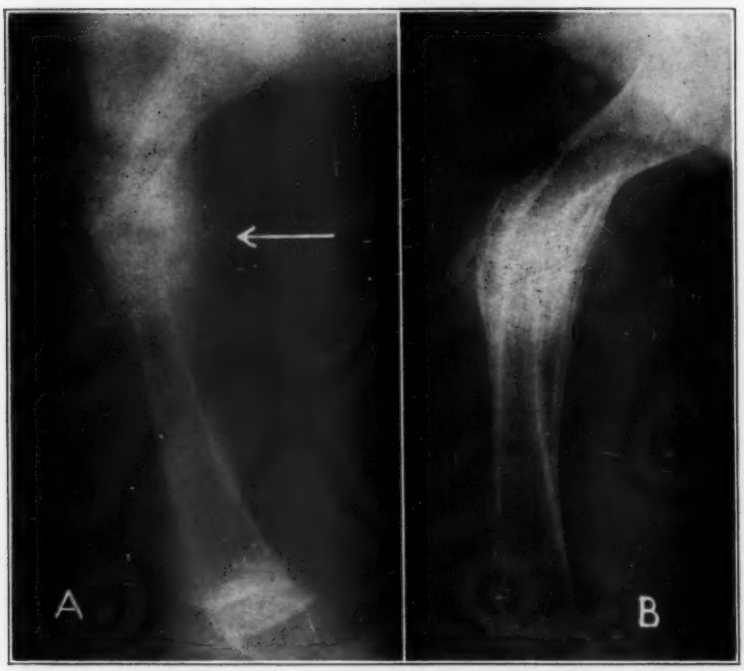

Fig. 4.—*A*, appearance of femur one month after the fracture shown in Figure 2, showing the excess of callus formation at the site of fracture; *B*, four months after the fracture. The apparent tumor at the site of fracture proved to be callus.

roentgenographed. The fractures were distributed thus: left radius, 4; right humerus, 2 (3?); left femur, 2; right femur, 1; right clavicle, 1; left ulna, 1, and skull, 1 (?).

All of the fractures were the result of comparatively slight trauma, and all, with the exception of those immediately preceding death, united readily. The deformities resulting from fractures were insignificant; but the long bones of all the extremities showed a certain amount of outward bowing, from infancy. One of the early fractures showed excessive callus formation, and in one other case a small cystlike rarefaction of the bone was noted.

TERMINOLOGY

Many names have been applied to this condition which is characterized by congenital bone fragility. Osteopsathyrosis, fragilitas ossium and osteogenesis imperfecta are the terms in common use in the English literature. "Idiopathic osteopsathyrosis" is accepted by most of the

Fig. 5.—Fracture of the left femur at 2 years and 9 months, shown here by raising of the periosteum. Both femurs show considerable bowing and flaring at the epiphyseal line.

continental writers. It has been pointed out that "fragilitas ossium" accentuates the chief clinical symptom of the disease, while "osteogenesis imperfecta" suggests the etiologic factor of imperfect bone formation.[2] Practically all writers use osteopsathyrosis and osteogenesis imperfecta

synonymously, but Griffith [1] reserves the latter name for cases of multiple intra-uterine fractures, together with imperfect development of membrane bone.

CLASSIFICATION OF CASES

Nichols [14] divides fragilitas ossium into two groups: (1) symptomatic fragility, in which fragility is due to one of various known pathologic processes, as rickets, old age, osteomyelitis, tuberculosis,

Fig. 6.—Fracture of the left radius in its upper third at 3 years.

tabes, syringomyelia, paralysis, malignant disease, bone cysts or ecchinococcus cysts, and (2) "idiopathic fragility," which is identical with osteogenesis imperfecta. Ostheimer describes two types of cases: (1) the fetal type found either at birth or shortly thereafter, with imperfect bone formation and multiple fractures (imperfect osteogenesis or periosteal dysplasia). Frequently these patients do not

14. Nichols, E. H., in Keen: Surgery: Its Principles and Practice, Philadelphia, W. B. Saunders Company **2**:56, 1914.

survive after the first year. (2) The congenital type found in infants and children, at birth or later, with fractures recurring often until puberty or even adult life, associated with similar bone changes (idiopathic osteopsathyrosis). These patients, with care, will survive but are often badly crippled. Locke [15] adds a third, the adult form, encountered as an idiopathic fragility of the bones after childhood.

Fig. 7.—Fracture of the left radius in its lower third at 4 years.

ETIOLOGY

No definite etiology for osteopsathyrosis has been determined. It occurs about equally in males and females. The hereditary factor has been recognized by many writers,[16] and the incidence of osteopsathy-

15. Locke, E. A.: Oxford Medicine, New York, Oxford University Press **4**:452, 1921.

16. Conard, H. S., and Davenport, C. B.: Hereditary Fragility of Bone, Bull. 14, Eugenics Record Office, Cold Spring Harbor, N. Y., November, 1915. (Includes a complete bibliography.)

rosis in persons with blue sclerae is sufficiently high to suggest that there is a definite relation between the two conditions.

The principal theories advanced as to the etiology are: (1) The disease is an affection of some central organ (osteotrophic organ) which furnishes some substance necessary for the normal formation and nutrition of bones;[6] (2) the disease is of nervous origin,[17] and (3) it is due to some disturbance of nutrition affecting the entire bone system during fetal life.[18]

Fig. 8.—Fracture of the right humerus at 4 years and 5 months.

PATHOLOGY

The disease apparently affects only the bones, as no constant pathologic condition has been found elsewhere in the body.

Growth of the bones in length usually proceeds normally, but the bones may appear to be much shortened because of bowing and angulation resulting from fractures. There is no constant gross deformity.

17. Biggs, M. H.: Univ. Penn. M. Bull. **15**:488, 1902-1903.
18. Harbitz, F.: Beitr. z. path. Anat. u. z. allg. Path. **30**:605, 1901.

In some cases, the bones have been described as being thin and delicate; but in many cases (as in the case described herewith), the bones appear to be proportioned normally. The extent of deformity usually depends on the number of fractures previously sustained, although (as cited above) there is often an intrinsic bowing of the long bones, entirely independent of traumatic deformities. This bowing is usually not so pronounced as that of rickets, and is confined to the diaphysis, in contrast to the epiphyseal deformities in rickets.

Fig. 9.—Fracture of the right clavicle at 5 years.

The skull is usually normal in size and shape in the older cases. In the early, fetal cases, the skull may be only a membranous sac with islands of calcification.

Microscopically, the bone usually shows a cortex which is thin and friable with occasional islands of cartilage. Trabeculae are often imperfectly formed or absent. Nichols [14] says that instead of osteoblasts depositing new bone on a cartilaginous matrix, the trabeculae are formed by calcification of cartilage cells. The dense bone formed is nonlaminated or imperfectly laminated, with no haversian canals but with large marrow spaces in which there are few trabeculae. The formation of periosteal bone is also abnormal and incomplete. Several writers have called attention to the fact that in this disease there is

increased absorption of bone but very scant bone proliferation. There is a difference of opinion concerning the relative amount of calcium salts present, it not being definitely determined that there is a lack of calcium in patients with osteopsathyrosis.

Fig. 10.—Marked anterior bowing and thickening of the midportion of the diaphyses of the bones of the lower leg at the time of fracture of the humerus, shown in Figure 9.

SYMPTOMATOLOGY

Aside from the tendency toward frequent fractures, there are practically no constant symptoms.

In some of the earlier cases, the appearance of the patients conforms more or less to type. They have a relatively large head, small chest,

Fig. 11.—Fracture of both bones of the left forearm at 7 years.

Fig. 12.—Refracture of the left radius at 7 years and 3 months, at the site of the previous fracture.

and a protuberant abdomen. The later cases, however, may show no recognizable peculiarities of form.

As has already been mentioned, in some patients there is a dark blue tint in the sclerae, which is said to be due to deficiency of the sclerotic fibrous tissue, allowing the pigment of the choroid to show through.

Character of the Fractures.—As the name suggests, the most characteristic symptom of the disease is the extreme brittleness of the bones

Fig. 13.—Characteristic deformity of the bones of the arm, three months before the patient's death.

and the ease with which fractures are sustained. The trauma is usually slight, and very often the signs of fracture are meager. Instances have been cited in which even the most careful handling of diseased infants or children caused fractures, and in other cases a mere handshake has been enough to break the forearm. Very little pain, tenderness or swelling is attendant on these fractures, mobility or deformity often being the only sign found. Frequently the child will show nothing

more than unwillingness to use the affected arm or leg. The tendency to fracture is bilateral, and both sides of the body are usually affected sooner or later. The long bones of the extremities, the clavicles and the ribs are the most common seats of fracture; but the other bones of the

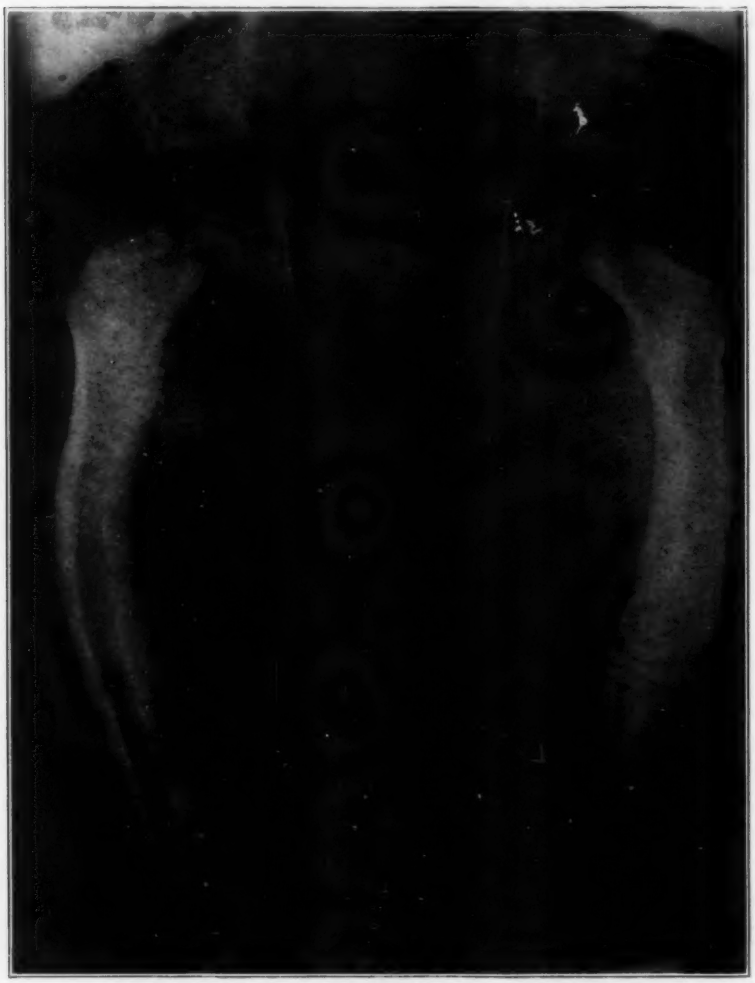

Fig. 14.—Characteristic deformity of the femurs, three months before the patient's death.

body are occasionally involved. The femur is the one bone most commonly broken in osteopsathyrosis (Locke). Fracture of the skull is comparatively rare.

Kienböck states that the periosteum is rarely ruptured. The callus forms in the usual way and is variable in amount. It is generally said

that these fractures unite more readily than those in normal bone, but Kienböck asserts that the healing may not be complete for several months. In support of his contention may be mentioned the fact that refracture occasionally occurs at the site of previous injury, several months after union is thought to be complete. Such an instance is cited in the case described herewith. Certainly most of the fractures in this case were followed by apparently firm union in shorter time than that

Fig. 15.—Characteristic deformity of the bones of the leg, three months before the patient's death.

required for most normal bones. Kienböck also asserts that the callus may be considerably hypertrophied, an instance of which peculiarity was noted above, following one of the early femur fractures (Fig. 4 *B*).

The number of fractures varies greatly, but few patients have less than ten. Terry [19] reports the case of a man, aged 42, with more than

19. Terry, W. I.: Hereditary Osteopsathyrosis, Ann. Surg. **68**:231 (Aug.) 1918.

sixty fractures. Mixsell records the case of Chaussier with 113 fractures. According to Emerson,[20] the tendency to fragility is lost if the patient lives to be 30; but he mentions one case in which the disease continued to the seventieth year.

Roentgen-Ray Appearances.—Locke [15] has admirably summarized the roentgen-ray findings noted by various authors, as follows: "(1) a high degree of osteoporosis uniformly affecting the entire skeleton,

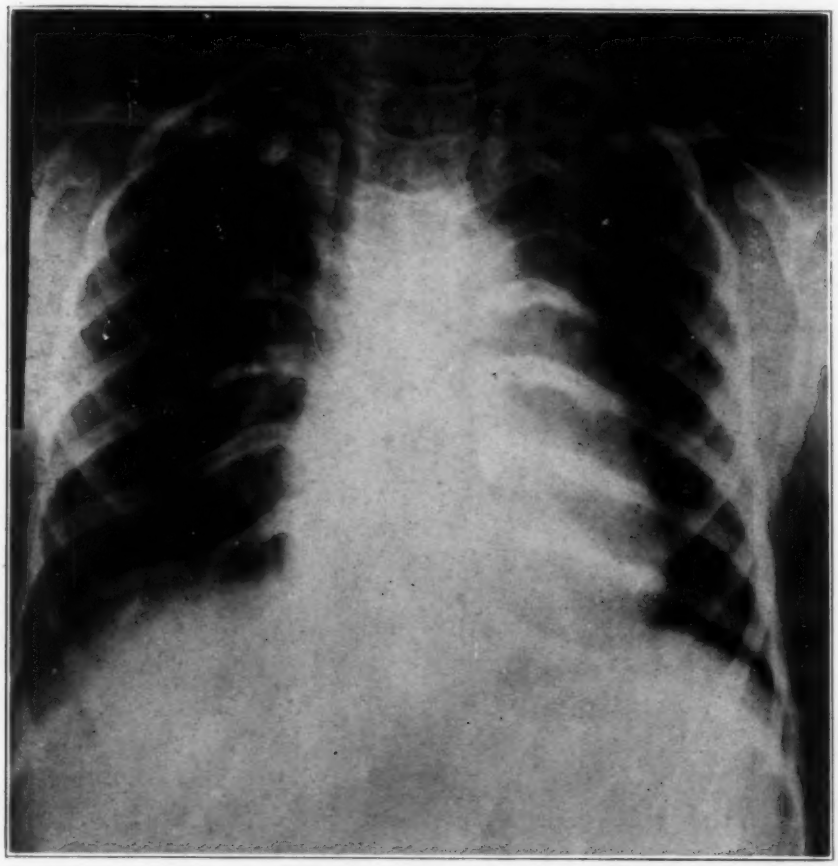

Fig. 16.—Appearance of the chest of the patient, three months before his death.

the variations in density giving a mottled appearance; (2) marked deformities of the long bones of the extremities, usually of the angular type, due to fractures, rarely also some actual bowing; (3) apparently normal size and shape of bones, except as altered by fractures and resulting callus formation; (4) often excess callus formation

20. Emerson, C. P., in Osler and McCrea: System of Medicine, New York, Oxford University Press **6**:723, 1909.

with variable degree of calcification. A transverse line of decalcification is often seen at the point of previous fracture; (5) the epiphyseal line is straight, cartilage is always thin; (6) a very faint shadow is given by all the bones, frequently scarcely more dense than that of the surrounding soft parts; (7) the cortex is thin, irregular and deficient in salts; (8) the spongiosa of both epiphysis and diaphysis is extremely faint with entire absence of normal markings; (9) the medullary cavity

Fig. 17.—Appearance of the skull of the patient, three months before his death.

is very irregular in outline and dilated." These changes are considerably less marked in some of the milder cases, such as the one described above.

Metabolism.—Several interesting metabolic studies on patients with osteopsathyrosis have been made within the last few years. While these studies have not been conclusive, they have suggested that calcium

metabolism may have some bearing on this type of bone fragility, as well as on the deformities of rickets. They have also suggested a method of treatment which may prove to be helpful.

Bookman [21] reported studies on a man, aged 27, with osteopsathyrosis, who had a healed fracture, five weeks before the time of the experiment. He found in this patient a markedly negative calcium balance (loss of 0.019 gm. of calcium monoxid per kilogram of body

Fig. 18.—Fracture of the right humerus at 7 years and 6 months. On comparing this illustration with Figure 8, it will be noted that the cortex of the diaphysis is relatively thinner than it was at the time the earlier roentgenogram was taken.

weight), and likens his to similar findings in osteomalacia. The negative balance is explained by the fact that in both conditions calcium from the already formed bone is being liberated and thrown out of the system.

21. Bookman, A.: The Metabolism in a Case of Idiopathic Osteopsathyrosis, Arch. Int. Med. **8**:675 (Nov.) 1911.

Schwarz and Bass [3] studied the metabolism of a 7 months old infant with osteogenesis imperfecta, who had had no fractures subsequent to the fourth day after birth. They found a practically normal, or positive, calcium balance (with retention of 0.109 gm.).

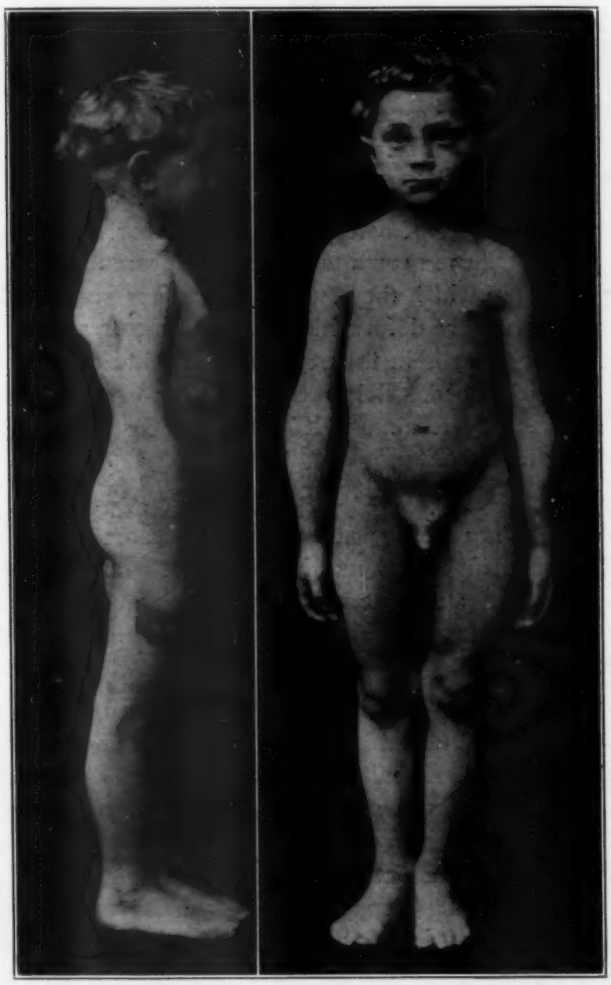

Fig. 19.—Appearance of patient at 7 years and 3 months.

Bamberg and Huldschinsky's [4] case showed a variation from a loss of 0.019 to a gain of 0.136 gm., the latter figure being obtained while the patient was under treatment with cod liver oil and phosphorus.

Bookman,[5] in his studies on a 3 months old infant with osteogenesis imperfecta, also found a low calcium retention, which, however, varied with the course of the disease. He also found that the deficient reten-

tion of calcium was favorably influenced by the administration of cod liver oil and phosphorus, and still more by calcium lactate. He believes that the similar results obtained in rickets suggest an etiologic relationship to osteopsathyrosis.

Ruggeri [10] studied the metabolism in a girl of 13, with a history of twelve fractures. He found that she had a daily high deficit in the phosphorus, calcium and magnesium balance. This balance was improved for a short time by the administration of thymus and suprarenal extracts, but gradually the condition returned to its original status within a few months.

PROGNOSIS

The outlook in cases of osteopsathyrosis is poor, in spite of the fact that a few patients have grown to adult life, apparently overcoming the bone fragility from which they suffered in earlier years. Most of the patients that survive are deformed by earlier fractures. Few fractures occur after the patient is in the early twenties, and after that time the prognosis is fairly good. Below that age, however, the mortality is high. The mortality is almost 100 per cent. in the fetal type, the majority dying in utero.

DIAGNOSIS

The diagnosis is usually perfectly clear, because there is no other congenital disease in which multiple fractures occur. Rickets and syphilis occasionally cause fractures in young children; but rarely more than two or three fractures occur in the same person as a result of these affections.

TREATMENT

The fractures are treated in the usual way, great care being taken to prevent distressing deformities, by preserving good alinement.

The metabolic studies already mentioned would point to the efficacy of cod liver oil and phosphorus, and in some cases they have seemed beneficial. Hess [8] uses a dose of 4 c.c., twice daily, of either of the following preparations: phosphorus, 0.01 gm., and cod liver oil, 60 c.c., or pure tribasic calcium phosphate, 6 gm., and cod liver oil, 60 c.c. Czerny [22] reports benefit from the use of 100 gm. daily of raw carrot juice, on the theory that osteopsathyrosis is an avitaminosis.

Care of the patient to prevent fractures is the most important single factor in the treatment of osteopsathyrosis.

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22. Czerny, A.: Berl. klin. Wchnschr. **61**:310, 1919; Deutsch. med. Wchnschr. **45**:259, 289 (March 6) 1919.

THE DELBET WALKING PLASTER FOR TREATMENT OF DELAYED UNION IN FRACTURES OF BOTH BONES OF THE LEG

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Delayed union is a common complication in fractures of both bones of the leg, especially those in the lower third. The term will be here used to describe those cases in which there are movement between the fragments and tenderness at the site of fracture, and in which the roentgenograms reveal open medullary cavities and little or no callus formation. Pseudarthrosis has not developed in these cases.

The treatment for delayed union has very generally been direct fixation of the broken ends by metal inserts or bone grafts. These methods may succeed; but in too many instances they have failed because a long period of immobilization has produced atrophic and poorly nourished fragments—conditions unfavorable to the production of callus or the proliferation of a bone graft. The patient has also been subjected to all the risks of a major operation, including the danger of sepsis. The clinical picture of these cases is characteristic, a withered limb and stiffness of the joints—both evidence of poor circulation and deficient nutrition.

The reverse of this picture may be produced by the substitution of a method that not only is simpler but also embodies a principle fundamental to the growth of bone—provision for the mechanical stimulation of the fragments.

Experience in the treatment of these cases has shown that this stimulus may be best supplied by active use of the limb in weight bearing, which not only improves the impaired circulation but stimulates the osteoblasts, with resulting production of callus. To allow such use of the limb in weight bearing, some apparatus is necessary which will prevent further displacement of the fragments and at the same time permit free circulation in the limb and active use of the muscles and joints. The Delbet ambulatory splint has proved a simple and efficient appliance in meeting these requirements.[1]

DESCRIPTION OF THE DELBET AMBULATORY SPLINT

The apparatus consists of lateral, molded plaster-of-Paris splints reaching from the knee to the junction of the skin of the sole with that

1. Mocquot, Pierre, and Caraven, J.: La marche directe dans les fractures de jambe, Rev. de chir. **40**:601, 1909.

of the upper part of the foot. Two molded plaster bands are passed about the lateral splints, one just below the knee, the other just above the malleoli. These bands bear, and cause the lateral splints to bear, against the tuberosity of the tibia and the head of the fibula above and against the malleoli below, thus preserving the length of the leg (Fig. 1).

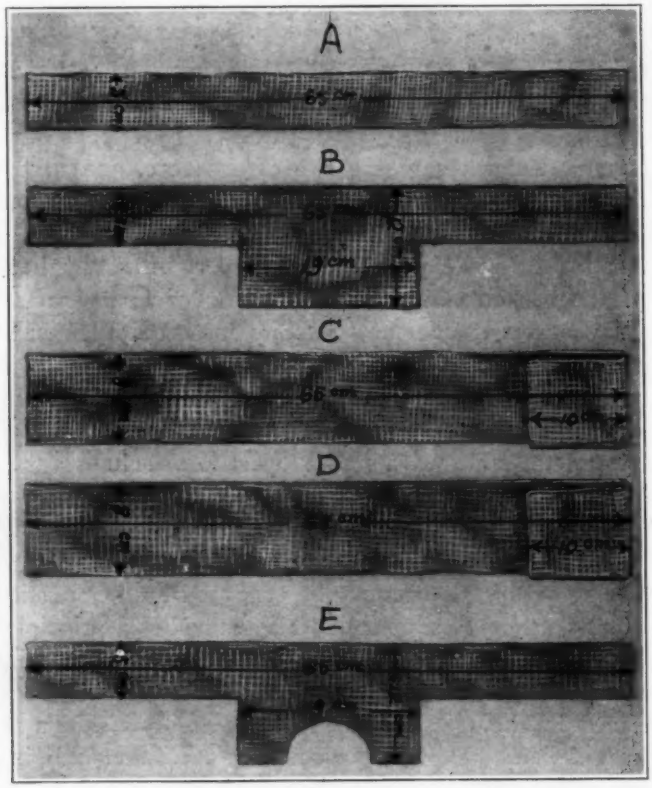

Fig. 1.—Method of cutting strips of crinoline to make the plaster bands for the Delbet ambulatory splint for fracture of the tibia and fibula: *A*, upper band; *B*, lower malleolar band; *C* and *D*, lateral bands with folds 10 cm. long at the inferior extremity, and *E*, lower band for the malleoli, with notch cut in the heel piece for the heel (from Leriche).

APPLICATION OF THE APPARATUS

The apparatus is applied directly to the shaved and greased skin. The two lateral molds are applied to the leg and held by assistants while the operator anchors them with the circular cuffs, one about the tuberosity of the tibia and the upper end of the fibula, the other just above the malleoli. The plaster is then carefully molded to the leg, especially about the tuberosity of the tibia and the malleoli. It is very essential

that the plaster be smooth in order to prevent irritation of the skin and the formation of pressure sores. A snug bandage is applied until the plaster has set. Figures 2 and 3 are front and side views of the Delbet splint applied.

At first the patient is allowed to walk using crutches, permitting only partial weight bearing. As soon as he has become accustomed

Figure 2

Figure 3

Fig. 2.—Anterior view of Delbet walking plaster.
Fig. 3.—Lateral view of Delbet walking plaster.

to the apparatus, the crutches are discarded and a cane substituted. In from a few days to a week, the patient is walking with no other support than that provided by the splint. It is essential that the patient be under close observation for at least the first few weeks of treatment to guard against undue pressure on the malleoli or tuberosities. It is a good practice to change the splint once a month in order to care for the skin and to determine the position of the fragments and the amount of union. Roentgenograms are taken once in six weeks to observe the callus production.

Fig. 4 (Case 1).—Ununited fracture of four months' duration, showing no callus.

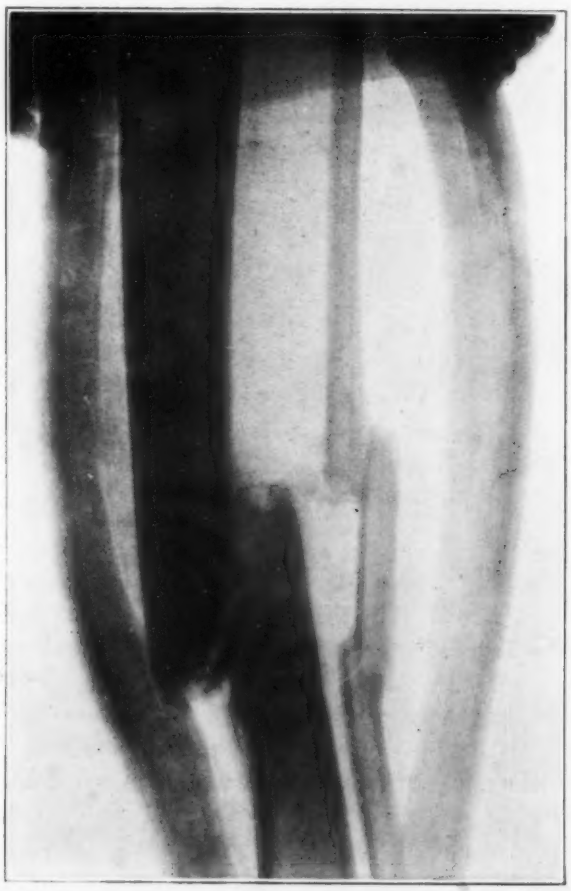

Fig. 5 (Case 1).—Marked increase in callus, three months after application of Delbet splint.

The results obtained have convinced us that cases of ununited fracture of both bones of the leg of several months' standing should be treated by some form of weight-bearing appliance, preferably the Delbet splint. It has enabled us to avoid operations in a number of instances. Case 1 is a good example of a very satisfactory result. This patient entered the hospital with an ununited fracture of both bones of the leg, of four months' duration. Previous treatment had been reduction

Fig. 6 (Case 1).—End-result, showing consolidation of callus.

followed by fixation in a plaster-of-Paris cast for a period of three months. The position of the fragments and the amount of callus, four months after injury, are shown in Figure 4. The leg was put in the Delbet splint for a period of three months, when union was firm. The amount of callus is shown in Figure 5. Figure 6, taken five months later, shows complete consolidation of the callus. Four months after admission, the patient was working as a hospital orderly without a splint and with free motion in the knee and ankle joints.

That this method has proved successful when operation with plating has failed is illustrated by Case 2 (Figs. 7, 8, 9 and 10). Three months after application of the plate at another hospital, there was no union. Two and one-half months after the application of the Delbet splint, union was firm and the roentgenograms revealed a definite production of callus.

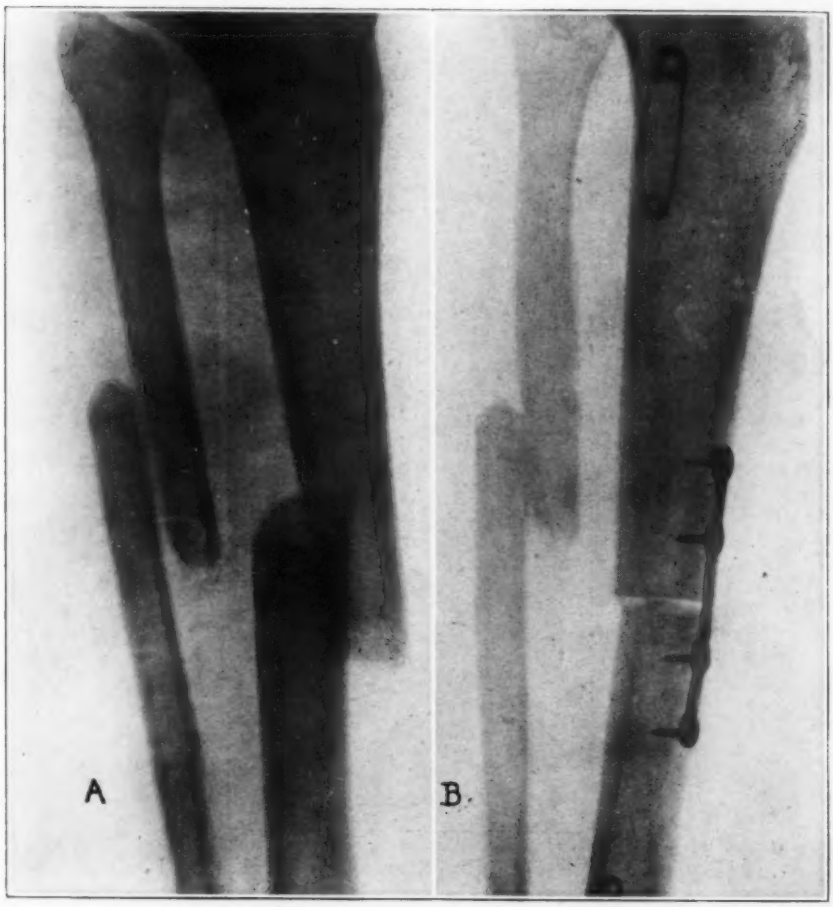

Fig. 7 (Case 2).—*A*, fracture with overriding of fragments; *B*, fracture, three months after operation, showing no callus.

Satisfactory results have also been obtained in cases in which operations had been performed either with or without bone grafts, the operation being followed by sepsis and osteomyelitis. Cases 3 and 4 are examples of this type. It is well known that mild infection of bone will often stimulate callus formation; but in these cases, two months of fixation in a satisfactory position failed to produce union. The use of

the Delbet splint for a period of from four to five months resulted in union. The progressive formation of callus is shown in Figure 11 (Case 3) and in Figures 12, 13 and 14 (Case 4).

REPORT OF CASES

CASE 1.—A teamster, aged 45, April 5, 1920, was struck by a log, causing fracture of both bones of the right leg at the middle third. The treatment consisted of reduction of the fracture and immobilization for a period of three

Fig. 8 (Case 2).—Callus forming, one month after application of Delbet splint.

months. At the end of that time, he was unable to bear weight on the leg because of weakness and pain at the site of fracture. He entered the University Hospital, Aug. 4, 1920.

Examination revealed an ununited fracture of both bones at the middle third of the leg; motion with pain at the site of fracture of the tibia, and three-fourths inch (1.9 cm.) shortening. The ankle joint was swollen and motion was limited. He was unable to bear weight on the leg because of pain. The Wassermann reaction was negative. The roentgenogram (Fig. 4),

taken Aug. 5, 1920, demonstrated an oblique fracture of the tibia with displacement and overriding of the fragments, double fracture of the fibula and little callus formation.

Aug. 9, 1920, a Delbet splint was applied and weight bearing begun. Limited motion of the ankle joint caused some pain on walking.

Sept. 21, 1920, the Delbet splint was removed. There was only slight motion between the fragments. A new Delbet splint was applied. The patient walked without other support.

Fig. 9 (Case 2).—Increase in callus, two months after application of Delbet splint.

Nov. 9, 1920, union was firm. Figure 5 shows the very decided increase in the amount of callus. The patient is working as an orderly in the hospital with no supportive apparatus. The ankle joint is only slightly limited in motion. A roentgenogram (Fig. 6), taken April 22, 1921, showed complete consolidation of the callus.

CASE 2.—A lumberman, aged 48, April 21, 1920, sustained a fracture of both bones of the leg at the junction of the upper and middle thirds. Figure 7 *A* shows the position of the bones, with marked overriding of the fragments. Operation was performed April 30, 1920. The fragments of the tibia were cut off, the ends apposed and a Lane plate applied. I saw the patient first, July 16, 1920. He was wearing a plaster cast and using crutches without weight

bearing. Examination revealed good alinement of the fragments, tenderness and motion, with pain at the site of fracture. The roentgenogram (Fig. 7 *B*), taken July 16, 1920, revealed perfect approximation of the fragments, but no evidence of union.

Aug. 15, 1920, a Delbet splint was applied.

Sept. 18, 1920, the Delbet splint was removed. Figure 8 shows the increase in callus formation.

Fig. 10 (Case 2).—Complete consolidation, four and one-half months after application of the Delbet splint.

Oct. 13, 1920, union was firm clinically, and the roentgenogram (Fig. 9), taken Oct. 13, 1920, shows the amount of callus formed after wearing the Delbet splint for two months.

Dec. 14, 1920, all apparatus was removed. Union was firm, and the ankle was only slightly limited in dorsiflexion.

Jan. 5, 1921, a roentgenogram (Fig. 10) revealed complete consolidation of the callus, four and one-half months after the application of the Delbet splint. There is a permanent shortening of 1½ inches (3.8 cm.), causing the patient to limp slightly. The plate was removed, Jan. 6, 1921. The wound healed by first intention.

CASE 3.—*History.*—A man, aged 42, May 28, 1920, sustained a fracture of both bones of the leg in an automobile accident. The fracture was reduced; a plaster-of-Paris cast was applied and maintained for a period of fourteen weeks. The plaster was then removed, and, as no evidence of union was found, the patient was operated on and a bone graft inserted. The leg was then fixed in plaster-of-Paris for a period of seven weeks. About four months after the injury, all fixation was removed. Dec. 29, 1920, the patient was sent to the University Hospital for treatment of nonunion.

Fig. 11 (Case 3).—*A*, ununited fracture of seven months' standing, showing evidence of fragments of bone graft; *B*, callus bridging fragments, four months after application of Delbet splint; C, end-result with union, seven months after application of Delbet splint.

Examination.—There was a linear scar over the internal aspect of the tibia of the left leg—site of the previous operation —and an ununited fracture of the tibia at the junction of the middle and lower thirds of the leg, free motion between the fragments with pain, and 1 inch (2.5 cm.) shortening. The roentgenogram (Fig. 11), taken Dec. 30, 1920, shows a fracture of both the tibia and fibula, with eburnation of the ends and some callus formation. Extending into the medullary canal of the proximal and distal fragments of the tibia is an old graft, with no union of either bone.

Diagnosis.—Pseudarthrosis of the tibia and fibula.

Operation.—Jan. 7, 1921, the ends of the fragments were freed and the sclerotic bone and old graft were removed. A new graft was cut in the form of a truncated cone and wedged across between the upper and lower fragments (after the method of Gallie). Periosteal grafts were then taken from the opposite leg and strips were placed on three sides of the tibia. During the application of the plaster, an assistant twisted the foot and, it was feared at that time, displaced the graft.

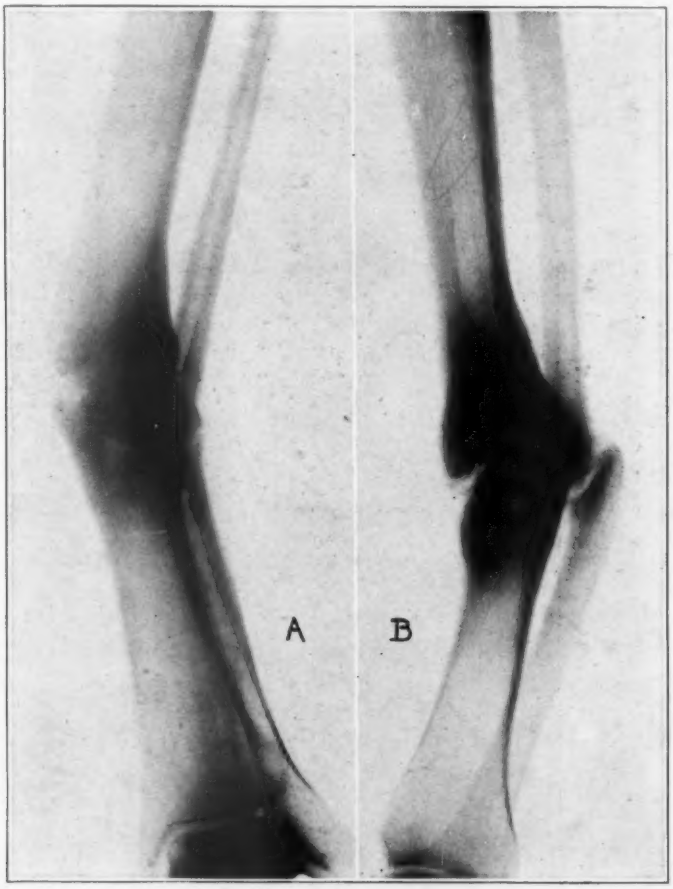

Fig. 12 (Case 4).—*A,* fracture with nonunion and marked internal bowing; *B,* lateral view.

Course.—Jan. 10, 1921, the plaster was split and the wound inspected. The graft was found to be displaced and to be sloughing its way through the skin. The removal of the graft was followed by sepsis. The plaster was therefore removed and a splint applied, holding the leg in good position and allowing for dressings.

Feb. 25, 1921, the sepsis had cleared up and the wound was granulating. There was no evidence of union. A Delbet walking splint was applied and the patient was encouraged to walk.

April 12, 1921, the patient had been walking with the Delbet splint for about six weeks. There was still motion between the fragments but it was not nearly so marked as before application of the Delbet splint. The patient was seen again, June 13, 1921, and the roentgenogram of the same date (Fig. 11 *B*) revealed definite production of callus between the fragments of both the tibia and fibula. Clinically, the union was quite firm.

Sept. 20, 1921, the roentgenogram (Fig. 11 *C*) demonstrated bony union. The patient walked without any support and did not complain of any pain. His only symptom was a feeling of weakness and slight limitation of motion in the ankle.

Fig. 13 (Case 4).—Mortising operation.

CASE 4.—*History.*—A man, aged 33, one year previously had been in an automobile wreck in which he sustained a compound fracture of the right tibia and fibula. The fracture was reduced and fixed in plaster for a period of seven weeks. Operation was then performed, the ends of the fragments being freshened but no internal fixation was used. A plaster-of-Paris cast was worn for three months subsequently. On removal there was motion between

the fragments. The patient had tried all sorts of treatment and supports of various kinds, but nonunion had been the result and in addition there was pronounced inward bowing at the site of fracture.

Examination.—Dec. 1, 1920, there was a scar, 4 inches (10 cm.) long, over the mesial surface of the tibia, with pronounced inward bowing at the site of fracture. There was motion between the fragments without pain, one-half inch (1.2 cm.) atrophy of the calf and 1 inch (2.5 cm.) shortening of the leg. The roentgenogram (Fig. 12), taken Dec. 2, 1920, revealed a simple transverse fracture between the middle and lower thirds of the tibia, with marked

Fig. 14 (Case 4).—Callus uniting all four fragments, four and one-half months after application of the Delbet splint.

sclerosis of the ends of the fragments and inward angulation of about 30 degrees. There was a space still present between the ends of the tibia and fibula. The diagnosis was pseudarthrosis.

Operation.—Dec. 8, 1920, the ends of the fragments were freed, a mortise was made and held by beef bone pegs. Figure 13 is a reproduction of a roentgenogram taken shortly after operation.

Course.—Dec. 20, 1920, the sutures were removed. There was no evidence of infection.

Jan. 2, 1921, at the upper portion of the wound, there was a small sinus discharging a thin serous material.

Jan. 11, 1921, the patient had had a rise in temperature, with swelling at the site of operation and formation of an abscess.

Jan. 12, 1921, an incision was made; drainage was established and the beef bone pegs were removed. From this time until the middle of March, dressings were required and the fragments were immobilized in a satisfactory position. March 17, the wound was granulating and there was free motion between the fragments. It was then decided to try to stimulate callus formation by the use of a Delbet splint. The splint was applied March 20.

April 24, 1921, the Delbet splint was removed. There was definite motion between the fragments, but there was not the freedom of motion which there had been before the Delbet splint was applied.

July 14, 1921, the patient returned and the Delbet splint was removed. Examination revealed firm union. The patient had been walking on a Delbet splint for about four months. The callus formation is shown in Figure 14. The patient was discharged wearing a brace to prevent any recurrence of the deformity.

BONE ATROPHY: A CLINICAL STUDY OF THE CHANGES IN BONE WHICH RESULT FROM NONUSE*

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ST. LOUIS

I. Introduction:
(1) Summary of previous experimental study;
(2) Object of present study.
II. Material studied:
(1) Adults;
(2) Children.
III. Relation between changes in bone as a result of lack of use and the cause of the nonuse.
IV. Character of changes in adults.
V. Character of changes during period of growth.
VI. Effect of nonuse on growth of bone.
VII. Effect of nonuse on regeneration of bone.
VIII. Recovery from bone atrophy.
IX. Summary.

I. INTRODUCTION

In a previous experimental study of the atrophic changes in bone which follow nonuse of an extremity, it was found that these changes were the same following nerve paralysis, joint injury and mechanic fixation of the extremity. The degree of atrophy of the bone was directly proportional to the degree of nonuse, regardless of the experimental method used to produce nonuse. Mechanical fixation produced as rapidly developing and as marked bone atrophy as nonuse due to section of nerves or injury to joints.

In this experimental study it was found that nonuse of an extremity of an adult resulted in the bones of this extremity becoming lighter, more fragile and more permeable to the roentgen ray. The length of the bones in adults was unchanged. The diameter of the shaft of the bone was slightly diminished. The diameter of the medullary canal was markedly increased. The cortex of the shaft was thus diminished in thickness. The trabeculae of the spongy bone became thinner, and in part disappeared. In prolonged nonuse, the cortical bone of the shaft became porous. If the period of nonuse of an extremity was concurrent with the period of growth of the individual, the processes of atrophy and growth operated together, and the bones of the nonused

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extremity showed not only the same initial changes as were found in the bones of the adults, but also changes which were the result of an inhibition of growth. The bones were relatively shortened; the diameter of the shafts was diminished; the diameter of the medullary canals was relatively increased, and the shape of the bones was altered. The power of regeneration, the chemical composition and the physical characteristics of bone as a tissue were not changed by nonuse.

In this experimental study, the conclusion was therefore reached that the process of bone atrophy was not a change in the characteristics of bone as a substance but that the process of bone atrophy is a change in the amount of bone present. The process of bone atrophy affects the size, shape, thickness, length, weight and texture of the whole bone; but the chemical composition, the physical characteristics and the regeneration of bone are not changed. Bone atrophy is a quantitative rather than a qualitative change.

The object of this study was to observe the changes in bone which result from lack of use of extremities in various clinical conditions, and to compare these observations with those made on experimental animals.

II. THE MATERIAL STUDIED

The material which was studied consisted of the following groups of cases: (1) poliomyelitis; (2) spastic paralysis; (3) peripheral nerve injuries; (4) Friedreich's ataxia; (5) pseudomuscular atrophy; (6) syringomyelia; (7) chronic infectious arthritis; (8) tuberculosis of bone; (9) acute pyogenic osteomyelitis; (10) ischemic contracture; (11) fracture; (12) congenital deformities, and (13) astasia abasia.

In those groups in which a large number of persons were available, cases were selected so as to include various ages and periods of existence of the disabling disease. In all cases, the age, the duration of the disability and the extent of the disability were obtained. When the lack of use was unilateral, the bones of both the used and nonused extremities were studied. The bones were studied by means of roentgen-ray examination. In some instances the bones were available for gross and microscopic study. The bones were studied as to length, thickness, diameter of the medullary canal, thickness of the cortex of the shaft and the number and thickness of the trabeculae of the cancellous bone. In children the epiphyseal cartilages were compared as to regularity and thickness. It was, of course, fully realized that measurements of bones from roentgenograms is at best not accurate; but great care was taken to have the bones as nearly as possible in the same position, and at the same distance from the tube and plate. Thus the measurements were accurate for comparison.

Changes in Bone Resulting from Nonuse in Adults.—The following examples illustrate the changes in bone in adults which result from lack of use:

CASE 1.—*Peripheral nerve injury.* A colored man, aged 26, two years previously had caught his left arm in a belt on a revolving wheel, following which there was complete motor and sensory paralysis of the entire left forearm and a motor paralysis of the left arm. There was no bone injury. Sixteen months previously the brachial plexus had been sutured. Since operation there had been only a slight recovery from the motor paralysis of the arm, and no recovery of motion in the forearm. Sensation was completely recovered slowly in the entire extremity. Examination revealed marked muscle atrophy of the entire extremity with no contractures.

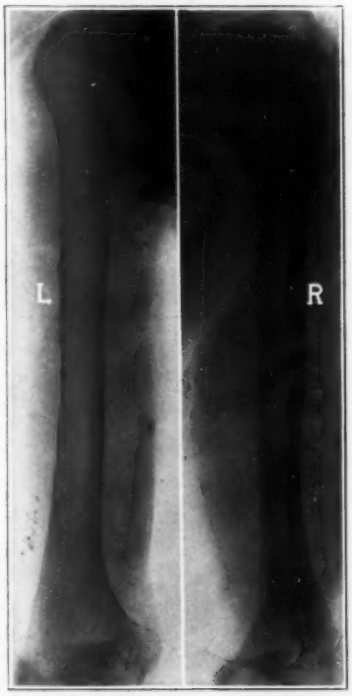

Fig. 1.—Roentgenogram of the right and left humerus in Case 1, a man, aged 26, with a brachial plexus injury of two years' duration. The marked diminution in thickness of the cortex of the shaft and of the left humerus, and the decreased density of the cancellous bone may be noted. The diameter of the medullary canal is markedly increased and the entire thickness of the shaft is slightly decreased. Compare the illustrations with the measurements recorded in the description of Case 1.

Roentgenograms of both humeri were studied. The right humerus appeared normal. The left humerus showed marked thinning of the cancellous bone of its extremities. There was a marked increase in the diameter of the medullary canal with a corresponding thinning of the cortical bone of the shaft. On close inspection linear striae of decreased density were noted in the cortical bone of the shaft (Fig. 1).

CASE 2.—*Spastic paralysis.* A man, aged 60, had an apoplectic stroke, thirteen months previously, which resulted in a complete right hemiplegia. Three months after onset, he was able to walk. There had been a gradual improvement in both the arm and leg. He was able to walk with only a slight limp at the time of examination. The right hand, however, had not recovered to the point of usefulness. There was a moderate flexion contracture of the hand and wrist. There was no demonstrable muscle atrophy. The circumferences of the forearms and calves were equal on the two sides. There was voluntary power in all muscles of the right arm and forearm.

Two years previously the patient had fractured the left radius near the wrist joint. From this injury there was a prompt and complete recovery.

Roentgenograms of both forearms and hands were studied. There was a very striking difference in the roentgenograms of the two hands. All of the bones of the right hand showed marked thinning of the cortex of the shafts due to increased diameters of the medullary cavities. The trabeculae of the cancellous bone were fewer in number and thinner. The shafts of the bones

TABLE 1.—MEASUREMENTS OF BONES IN CASE 1

	Right, Cm.	Left, Cm.
Length	32.0	32.0
Diameter at middle of shaft	2.3	2.1
Diameter of medullary canal (middle of shaft)	1.1	1.6
Thickness of cortex (middle of shaft)	0.6	0.25

TABLE 2.—MEASUREMENTS OF BONES IN CASE 3

	Right Radius, Cm.	Left Radius, Cm.	Right Tibia, Cm.	Left Tibia, Cm.
Length	24.1	24.6	37.5	37.3
Diameter of shaft	1.7	1.5	3.1	2.6
Diameter of medullary canal	0.7	0.6		
Thickness of cortex	0.5	0.45		

showed evidences of increased porosity as well as decrease in thickness. A difference in the bones of the forearm was distinct but less marked than it was in the bones of the hand. The left radius showed a healed Colles' fracture.

The contracture of the right hand did not permit the taking of roentgenograms from which comparative measurements would have been of any value (Fig. 2).

CASE 3.—*Syringomyelia.* A white man, aged 38, at the age of 14 years, noticed a weakness in the left arm. At 17 years of age, a weakness of the left leg was noticed. There was a similar weakness in the right arm and right leg at the ages of 29 and 32. The weakness progressed until eight years previously, when he could get about only with assistance. For the last two years the patient had been able to get only from a bed to a chair. On examination he presented the characteristic picture of advanced syringomyelia, with marked muscle weakness and muscle atrophy of the extremities. There was a complete dissociation of sensation, but no complete muscle paralysis. The skin of both hands and feet showed typical "trophic" ulcers.

Roentgenograms of all the bones of the extremities were studied.

The bones of both arms and legs showed abnormal thinness of the cortex of the shafts and of the cancellous bone of the extremities. The cortical bone of the shafts of all bones was slightly more porous than normally. In gen-

eral the bone atrophy was not advanced. There was, however, a definite correspondence in the amount of bone atrophy and the extent of loss of function in the extremities. There was no evidence of any influence on the normal growth of the bones in length or shape (Fig. 3).

CASE 4.—*Ischemic contracture.* A white boy, aged 16 years, one year previously fell and fractured the left radius. Splints were applied and a typical ischemic contracture developed. On examination there was a flexion contracture of the left hand and wrist with marked muscle atrophy and complete

Fig. 2.—Roentgenogram of the bones of the forearms and hands in Case 2, a man, aged 60, suffering from a right hemiplegia of thirteen months' duration. The atrophic changes in the bones of the right extremity are not so well shown in the reproductions as in the original plates. A marked difference, however, can be seen in the appearance of the right and left first metatarsal bones.

disability. There was very slight motion in the fingers. The contracture was overcome by excision of the carpus. Roentgenograms were made of both forearms and hands after the contracture had been relieved.

The bones of the left hand and forearm showed marked bone changes. There was a healed fracture of the radius in the distal third. The cancellous bone of the distal ends of the radius and ulna was markedly thin. There was

thinning of the cortex of the shafts of all the bones in the hand and forearm. The diameter of the shafts of all bones was slightly decreased. There was a decrease in length of both bones of the forearm. The epiphyseal lines were completely absent in all bones of the left forearm. The distal epiphyseal line of the right radius was present.

CASE 5.—*Infectious arthritis.* A white woman, aged 52, six years previously received a crushing injury to her right foot, which was followed by an infection of the tarsal bones. The infection resulted in destruction of the cuneiform bones and parts of the astragalus and os calcis. The infection healed with an extreme valgus deformity of the foot. There was no infection of the tibia or fibula. The patient had not used the right leg since the injury. She got about on the left leg with the assistance of crutches. There was marked muscle atrophy in the right calf. Roentgenograms of both tibias were studied.

There was a very marked difference in the appearance of the two tibias. The left tibia appeared normal. The right tibia showed extreme thinning of

TABLE 3.—MEASUREMENTS OF BONES IN CASE 4

	Right Radius, Cm.	Left Radius, Cm.
Length	23.4	22.4
Diameter of shaft	1.3	1.1
Diameter of medullary canal	0 6	0.5

TABLE 4.—MEASUREMENTS OF BONES IN CASE 5

	Right Tibia, Cm.	Left Tibia, Cm.
Length	38.8	38.0
Diameter of shaft	2.6	2.6
Diameter of medullary canal	2.4	1.9
Thickness of cortex of shaft	0.1	0.35

the cancellous bone of its extremities. The medullary canal was markedly increased in diameter. The cortical bone of the shaft was thin and porous. The diameter of the shaft was not decreased. The right tibia measured slightly longer than the left (Fig. 5).

CASE 6.—*Fracture.* A white man, aged 56, two years previously was struck by a heavy piece of lumber which broke both bones of the left leg. The fracture was compound, but no suppuration followed, and the small open wound closed in a few days. The fracture was treated with plaster but failed to unite. The patient had borne no weight on the left leg since the accident. He got about using the right leg and crutches. Examination revealed a nonunited fracture of the left tibia and fibula at the junction of the middle and distal thirds. There was free, painless, false motion at the level of the fracture. Roentgenograms of both tibias were studied, and the character of the bone of the left tibia and fibula was observed at operation, which was performed for the cure of the nonunited fracture.

The bones of the left leg and foot showed extreme bone atrophy. The cancellous bone of the extremities of the long bones and of the entire tarsal bones was very thin. The trabeculae were decreased in number and density. The medullary canal of the long bones was increased in size. The cortex of the shafts of the long bones was thin and porous.

Changes in Bone Resulting from Lack of Use During Growth.—The following cases were chosen as examples showing the changes in bone which result from lack of use during the growing period.

CASE 7.—*Peripheral nerve injury.* A white girl, aged 9 years, had a single congenital dislocation of the left hip. The deformity was such that the patient got about with a slight limp. There was no apparent muscle atrophy. An open operation was performed, and the dislocation was reduced. Immediately following operation, there was a complete sciatic nerve paralysis. The patient

Fig. 3.—Roentgenogram of the bones of the left upper extremity in Case 3, a man, aged 38, suffering from syringomyelia. The first symptoms of the disease appeared twenty-four years previously. The progress had been slow and the sensory paralysis was much more advanced than the motor paralysis. The bones show a moderate degree of atrophy.

was under observation for a period of five years after the nerve injury. At the end of this period there was some recovery of sensation. There was a slight return of power in the hamstring muscles. Otherwise, there was a complete motor paralysis of all muscles supplied by the sciatic nerve, with marked muscle atrophy. The patient was unable to use the leg in walking. Roentgenograms of both lower extremities were made five years after the nerve injury. Those of both tibias were studied in detail.

The bones of the right leg appeared normal for a 14 year old child. Both epiphyseal cartilages were present in both bones. The contours of both tibias and fibulas were normal. Both bones of the left leg were abnormal. The fibula had a very small shaft. The epiphyses were large in comparison with the shaft, but were smaller than normal. Both epiphyseal cartilages of the fibula were absent. The left tibia showed a decrease in the diameter of the shaft, and a relative increase in the diameter of the medullary canal. The epiphyses of the tibia were large in comparison with the shaft, but smaller than those of the normal tibia. The cortex of the shaft was thinner than that of the right tibia. The proximal epiphyseal cartilage was apparently absent. The distal cartilage showed faintly. The lengths of both tibias and fibulas were diminished (Fig. 7).

TABLE 5.—MEASUREMENTS OF BONES IN CASE 7

	Right Tibia, Cm.	Left Tibia, Cm.
Length	33.5	32.5
Diameter of shaft	2.1	1.8
Diameter of medullary canal	1.3	1.2
Thickness of cortex of shaft	0.4	0.3
Diameter of proximal epiphyses	7.0	6.5

TABLE 6.—MEASUREMENTS OF BONES IN CASE 8

	Right Tibia, Cm.	Left Tiba, Cm.	Right Femur, Cm.	Left Femur, Cm.
Length	28.9	30.2	35.2	36.0
Diameter of shaft	1.5	1.7	1.7	1.9
Diameter of medullary canal	0.9	1.0	0 9	0.9
Thickness of cortex	0.3	0.35	0.4	0.5
Diameter of epiphysis	5.7	6.3	6.6	7.0

TABLE 7.—MEASUREMENTS OF BONES IN CASE 9

	Right Radius, Cm.	Left Radius, Cm.
Length	19.5	25.0
Diameter of shaft	1.3	1.6
Diameter of medullary canal	0.8	0.25
Diameter of epiphysis (distal)	2.7	3.6

CASE 8.—*Spastic paralysis.* A colored girl, aged 11 years, had had a right hemiplegia since birth. She was restless and feebleminded and had never walked. The right leg and arm showed the typical picture of complete spastic paralysis. The left arm and leg were not paralyzed.

Roentgenograms of the bones of both lower extremities were studied. All the bones of both extremities showed distinct evidence of lack of function. The changes in the bones of the right lower extremity were much more marked than in the left (Fig. 8).

CASE 9.—*Ischemic contracture.* A white boy, aged 17 years, at the age of 10 years fell from a tree and fractured the bones of the right forearm. Splints were immediately applied to the arm. There was a great deal of pain. The splints were not removed for two weeks. When the dressings were removed, there was extensive ulceration of the skin of both anterior and posterior surfaces of the wrist and palm. The fingers could not be straightened. Grad-

ually a marked flexion contracture developed. The hand had not been used since injury—the thumb was adducted across the palm. There were deep scars on the flexor and extensor surfaces of the wrist, as well as a deep scar on the thenar eminence. The muscles of the forearm were markedly atrophied. There was no evidence of sensory or motor paralysis. The entire forearm and hand were shorter and smaller than normal. The patient did not use the hand.

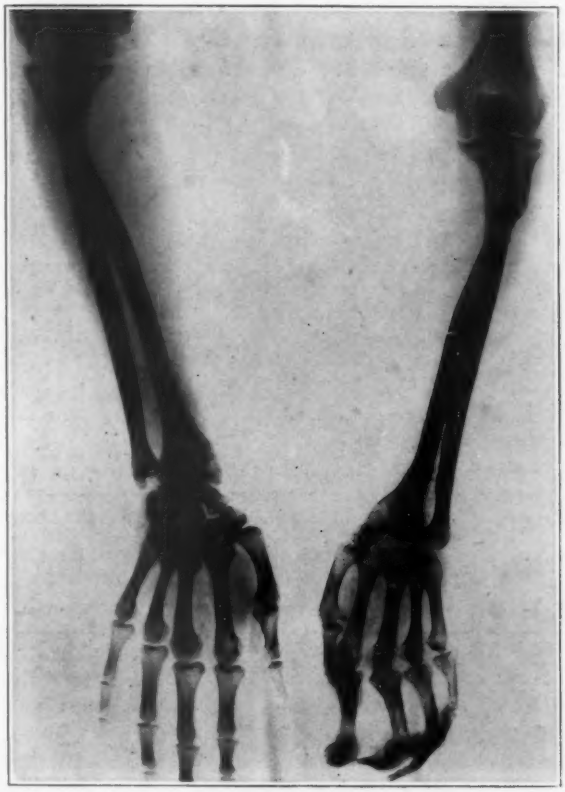

Fig. 4.—Roentgenogram of the bones of both forearms in Case 4, a boy, aged 16 years, suffering from an ischemic contracture of the left forearm, of one year's duration. There is a diminution in size and density of all of the bones of the left forearm and hand. The atrophic changes in the bones of the forearm are more marked in the distal portions of the bones. The distal epiphyseal cartilages of the left ulna and radius are absent.

Roentgenograms of both forearms and hands were studied. There was a marked diminution in the size and length of all bones of the right forearm and hand. The distal end of the radius and ulna showed more marked changes than the proximal ends. The cancellous bone of the distal end of the radius and of the bones of the hand was more porous. The diameter of the shafts of the bones was relatively decreased. The medullary canals were relatively increased. The cortex of the shaft was the same as that of the normal

extremity. The epiphyseal lines were present in the bones of the left forearm. The epiphyseal lines of the bones of the right forearm had disappeared (Fig. 9).

CASE 10.—*Tuberculosis of hip.* A white girl, aged 6 years, two years before had begun to limp. One year previously, examination revealed the typical clinical picture of tuberculosis of the hip. There was at this time only slight bone destruction in the right acetabulum. The right knee was slightly swollen and tender. Roentgen-ray examination disclosed no bone destruction at the knee. Tuberculosis of the knee was suspected, but could not be proved. The patient was treated by traction in bed for six weeks, after which a spica cast was applied to the entire right lower extremity. The patient has been continuously in a cast for a year. The cast had been changed four times during this period, but had never been off for more than a day. The patient had been able to get about with crutches and a high sole on the left shoe, for the last three months. For the last six months there had been no fever and the general condition of the patient had been very good.

TABLE 8.—MEASUREMENTS OF BONES IN CASE 10

	Right Tibia, Cm.	Left Tibia, Cm.
Length	27.2	27.0
Diameter of shaft	1.3	1.6
Diameter of medullary canal	1.0	1.0
Thickness of cortex	0.30	0.15
Diameter of epiphysis	5.4	5.0

TABLE 9.—MEASUREMENTS OF BONES IN CASE 11

	Right Tibia, Cm.	Left Tibia, Cm.	Right Femur, Cm.	Left Femur, Cm.
Length	34.0	33.6	....	....
Diameter of shaft	2.1	1.9	2.6	2.4
Medullary canal	1.4	1.3	1.6	1.5
Diameter of epiphysis	7.0	6.8	....	....

Examination immediately after removal of the cast revealed very little motion in the right hip and knee. There was marked muscle atrophy of all the muscles of the right thigh and leg.

Roentgenograms of all the bones of both lower extremities were studied. The right hip joint showed extensive destruction of the acetabulum and head of the femur. There was no evidence of a tuberculous focus in the region of the knee joint. All bones of the right lower extremity showed extreme atrophic changes. The tibia was chosen for comparative study since this bone was not involved in the disease process.

The right tibia showed a marked decrease in density of the cancellous bone. The diameter of the shaft was decreased; the cortex was thinner; the right tibia was slightly longer than the left; the epiphyseal lines were all present. The epiphyseal lines in the right tibia were abnormally regular (Fig. 10).

CASE 11.—*Osteomyelitis of femur.* A white girl, aged 12 years, at the age of 6 years had suffered from acute osteomyelitis which involved the distal end of the left femur. The site of the infection was opened and drained. There was a discharge from the bone for a period of one year. The wound then closed, with the gradual reestablishment of normal function in the extremity. For a period of eight months, the left lower extremity was not used. At

the present time there is slight atrophy of the muscles in the thigh and calf on the affected side. Roentgenograms of the bones of both lower extremities were studied.

All the bones of the left lower extremity were slightly smaller in all measurements. The trabeculae of the cancellous bone were fewer in number but thicker, presenting the appearance of a coarser network. The epiphyseal lines were all present and did not vary on the two sides (Fig. 11).

The patient had a short period of nonuse during the growing period, which was followed by complete return of use of the extremity.

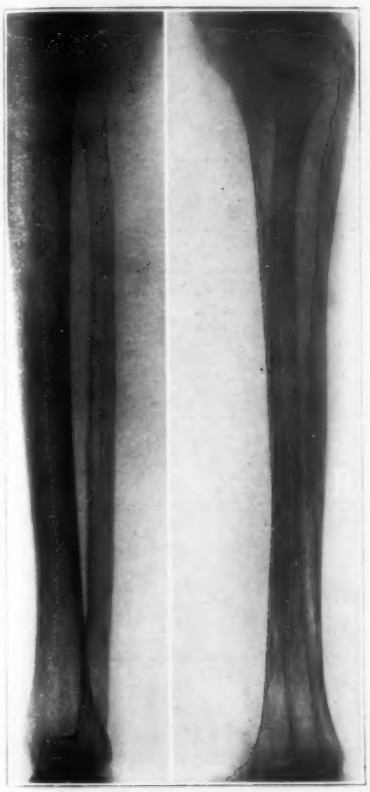

Figure 5

Figure 6

Fig. 5.—Roentgenogram of the bones of both legs in Case 5, a woman, aged 52, who had not used her right leg for a period of six years because of a deformity of the foot which followed an acute infectious process in the tarsus. The bones of the right leg show advanced nonuse atrophy. The thick, compact cortex of the shaft of the right tibia is changed to thin porous bone. The illustration is characteristic of advanced bone atrophy which results from lack of use during the adult period.

Fig. 6.—Roentgenogram of bones of the legs in Case 6, a man, aged 56, with a nonunited fracture of the left leg of two years' duration. The bones of the left leg, foot and ankle show marked atrophy.

CASE 12.—*Fracture.* A white boy, aged 14 years, at the age of 8 years fell and fractured the shaft of the right femur. The fracture healed in good position, and function was restored. Since this accident, however, the right femur had been refractured seven times, each time the result of a fall. The patient was first seen by us in October, 1920, at which time there was a lack of union in the eighth fracture of the shaft of the right femur, which had been sustained two months previously. The fracture had been treated by application of a plaster cast. The patient stated that each preceding fracture had been treated in a similar manner. Examination in October, 1920, revealed false motion in the middle third of the right femur. Roentgenograms disclosed lack of approximation of the fragments. Roentgenograms were made of all the bones of the body. There was nothing abnormal except in the bones of the right lower extremity. All bones of this extremity showed atrophic changes. There was marked decrease in the density of the cancellous and cortical bones. The bones were diminished in thickness and length as compared with the corresponding bones of the left extremity. All epiphyseal cartilages were

TABLE 10.—MEASUREMENTS OF BONES IN CASE 12

	October, 1920		February, 1922	
	Left Tibia, Cm.	Right Tibia, Cm.	Left Tibia, Cm.	Right Tibia, Cm.
Length	32.3	29.8	33.3	29.9
Diameter	2.0	1.7	2.2	1.9
Diameter of medullary canal	1.0	1.0	1.0	0.9
Thickness of cortex	0.45	0.35	0.6	0.5
Diameter of epiphyses	....	....	7.7	6.9

TABLE 11.—MEASUREMENTS OF BONES IN CASE 13

	Right Tibia, Cm.	Left Tibia, Cm.	Right Fibula, Cm.	Left Fibula, Cm.
Length	40.0	39.0	34.0	34.0
Diameter of shaft	2.5	2.0	1.5	0.5
Diameter of medullary canal	1.3	1.4	. .	....
Diameter of epiphyses	8.5	7.6	....	....
Thickness of cortex	0.6	0.3	....	....

present (Fig. 12). The fracture was treated by open operation and bone transplantation. The fracture united in twelve weeks. The patient then got about on crutches for a period of about six weeks, after which time he walked with no support. For the last year the patient had been using the extremity, with an extension sole for complete weight bearing. In February, 1922, the entire right lower extremity was smaller and shorter than the left. The measured shortening amounted to 3.5 inches (8.9 cm.). Roentgenograms of the bones of both lower extremities were obtained.

In this patient, therefore, there was a period between the ages of 8 and 14 years in which there was a marked lack of use of one lower extremity as a result of repeated fractures. Finally there was a year of continuous usefulness of the extremity. Roentgenograms were obtained at the beginning and end of this period of usefulness of the extremity. This permitted the study of the changes which result from lack of use and also the effect on the bones of reestablishment of function. Furthermore, the period of observation was during the latter years of growth of the patient.

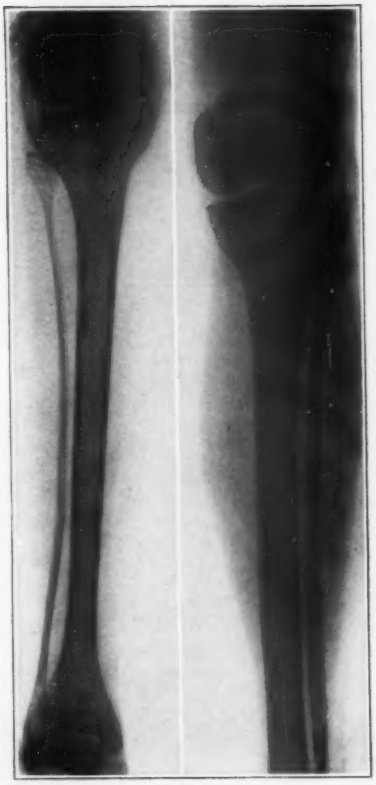

Figure 7

Figure 8

Fig. 7.—Roentgenogram of the bones of the legs in Case 7, a girl, aged 14 years, who had a complete muscle paralysis of the left leg due to injury of the sciatic nerve five years previously. Compare the shape and the appearance of the epiphyseal cartilages of the tibias. The measurements of the bones are recorded in the description of Case 7.

Fig. 8.—Roentgenogram of the bones of the lower extremities in Case 8, a girl, aged 11 years, who had suffered from a right hemiplegia since birth. Compare the bones of the two extremities with the measurements recorded in the description of Case 8.

Roentgenograms of the bones of both lower extremities taken in 1922 demonstrated the bones of the affected extremity to be smaller and shorter than those of the normal extremity. The left tibia had increased in all dimensions. The right tibia had increased in thickness but not in length. All epiphyseal cartilages in the bones of the right extremity were absent. The proximal epiphyseal cartilages of the left tibia and fibula were faintly visible. There was a marked difference in the appearance of the cancellous bone of the right tibia from that seen in the left tibia and also from that seen in the right in the roentgenograms studied a year previously. The trabeculae of the can-

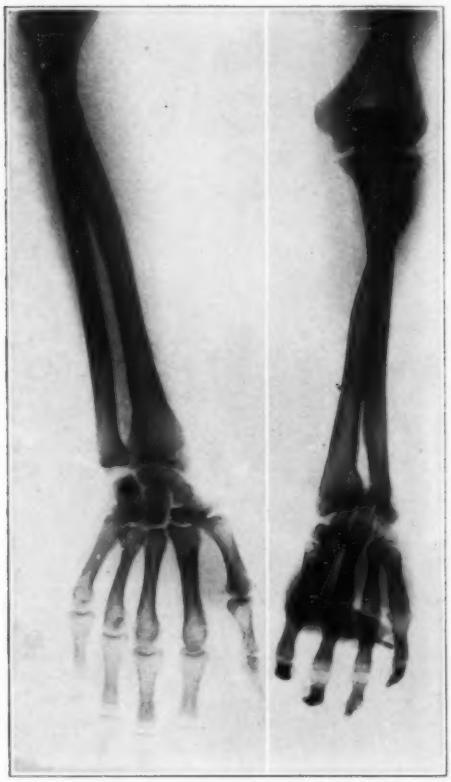

Figure 9

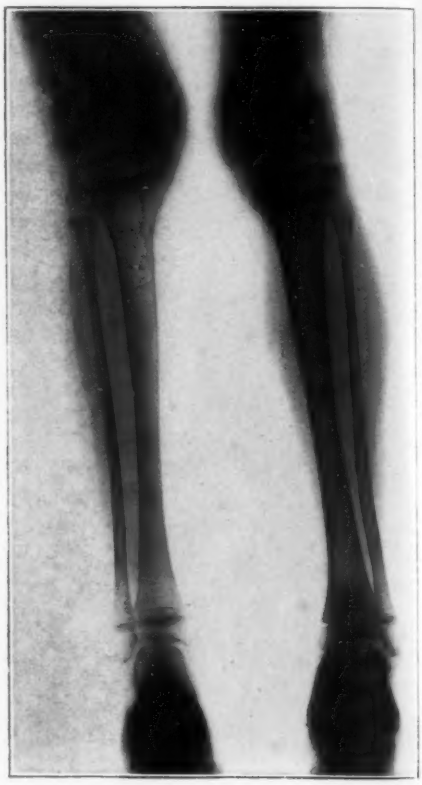

Figure 10

Fig. 9.—Roentgenogram of the bones of the forearms in Case 9, a boy, aged 17 years, with an ischemic contracture of the right forearm and hand. The disproportion of size of the bones of the right forearm and hand may be noted. The disproportion in length is greater than has been observed in other cases of nonuse. The epiphyseal cartilage may have been injured at the time of onset of the disease.

Fig. 10.—Roentgenogram of the bones of the legs in Case 10, a child, aged 6 years, with tuberculosis of the right hip of two years' duration. The entire extremity had been fixed in plaster for one year. The marked difference in the bones of the extremities may be noted. Compare the atrophic bones of the right leg with the illustrations of bone atrophy resulting from poliomyelitis.

cellous bone in the right tibia were fewer in number than in the corresponding areas of the left tibia, the individual trabeculae of the right tibia were thicker than in the left tibia and also thicker than in the right tibia of one year ago (Fig. 13).

CASE 13.—*Congenital deformity.* A white boy, aged 15, was born with a unilateral left talipes equinovarus of marked degree. The patient began to walk at the usual age. There had been one operative effort made to correct the deformity. At the time of examination the patient walked without artificial support. The weight was borne on the distal ends of the lateral metatarsals. There was a marked limp and disability in gait. The muscles of the left thigh and calf were much smaller than those of the right.

Roentgenograms of the bones of both legs were studied. The bones of the right leg appeared normal. The bones of the left leg were thinner and shorter than normally. The cancellous bone was more porous than normally and the cortex of the shaft was diminished in thickness. The left fibula was strikingly thin. It was interesting to note, however, that the length of the left fibula and the right fibula was the same. All epiphyseal cartilages were present. Those in the bones of the left leg were more nearly closed than those in the bones of the right leg (Fig. 14).

TABLE 12.—MEASUREMENTS OF BONES IN CASE 14

	Lateral Roentgenograms Oct. 28, 1920		Anteroposterior Roentgenograms Jan. 19, 1921		Dec. 12, 1921	
	Right Tibia, Cm.	Left Tibia, Cm.	Right Tibia, Cm.	Left Tibia, Cm.	Right Tibia, Cm.	Left Tibia, Cm.
Length	23.4	23.3	23.5	23.4	24.7	24.7
Diameter of shaft	1.8	1.7	1.7	1.7	1.5	1.4
Diameter of medullary canal	0.7	0.7	1.0	1.0	1.3	1.1
Diameter of proximal epiphysis	2.7	2.6	4.1	4.1	4.3	4.3
Thickness of cortex	0.55	0.5	0 35	0 35	0.1	0.15

CASE 14.—*Poliomyelitis.* A girl, aged 5 years, was first seen in September, 1920, suffering from an acute attack of anterior poliomyelitis. The paralysis was complete in all extremities. The patient was under observation at the time of examination. There had been some recovery of motion in both upper extremities; but the lower extremities remained in a state of completely flaccid paralysis. The patient had been confined continuously to bed and to a chair. Roentgenograms of the bones of both legs were made Oct. 20, 1920, Jan. 19, 1921, and Dec. 12, 1921.

Roentgenograms made Oct. 28, 1920, one month after onset of the disease, revealed normal appearing bones. In the roentgenograms made Jan. 19, 1921, three months later, there was a marked change in the appearance of the bones of both legs. The cancellous bone was much more porous. The cortical bone of the shaft was much thinner and showed linear striae of decreased density. There was a slight increase in length of the bones of both legs. Measurements of the diameters of the shafts and medullary cavities cannot be accurately compared because the roentgenograms taken in October, 1920, were lateral views and those made in January, 1921, were anteroposterior views.

The roentgenograms made Dec. 12, 1921, fourteen months after the onset of the disease, were taken under the same conditions as those made Jan. 19, 1921. A comparison of these two roentgenograms, therefore, demonstrates accurately

the progress of the bone changes during a period of eleven months of complete lack of use in a growing child. The bones of both legs had become exceedingly thin. The trabeculae of the cancellous bone were much fewer and smaller. The thickness of the cortex had decreased markedly. The length of the bones had increased. The diameter of the shafts had decreased. The diameter of the medullary canals had increased. The width of the epiphyses had increased. Thus, the contours of the bones had changed (Figs. 15, 16 and 17).

Case 15.—A white woman, aged 25, at the age of 4 years had an attack of acute anterior poliomyelitis which resulted in a complete paralysis of all the muscles of the left leg and a partial paralysis of the left thigh. Since the onset of the paralysis, the left lower extremity had not been used for walking. The patient had always walked with crutches and there had been no attempt at any time to make use of the paralyzed extremity either with or without artificial support. Examination revealed complete paralysis of the leg with marked muscle atrophy. The adductor group and the psoas muscles of the thigh had some power, otherwise the thigh muscles were completely paralyzed and atrophied.

TABLE 13.—Measurement of Bones in Case 15

	Right Tibia, Cm.	Left Tibia, Cm.
Length	40.0	34.6
Diameter of shaft	2.7	1.9
Diameter of medullary canal	1.7	1.1
Diameter of epiphysis (proximal)	7.8	6.6
Thickness of cortex	0.5	0.4

TABLE 14.—Measurements of Bones in Case 16

	Right Tibia, Cm.	Left Tibia, Cm.
Length	35.1	37.0
Diameter of shaft	2.4	2.6
Diameter of medullary canal	1.7	1.7
Diameter of epiphyses (proximal)	7.3	8.3
Thickness of cortex	0.35	0.45

Roentgenograms of the bones of both lower extremities were studied. All of the bones of the left lower extremity, including the bones of the left pelvic girdle, were diminished in size and density. There was an extreme coxa valga deformity of the left femur, associated with a lack of development of the great trochanter and a relative overdevelopment of the lesser trochanter. The acetabulum was small and shallow. All epiphyseal cartilages were absent. The tibias were chosen for detailed comparative study. The right tibia appeared normal. The left tibia was shorter. The diameter of the shaft was diminished. The epiphyses were smaller than those of the left tibia, but in comparison to the size of the shaft they were large. The cancellous bone was more porous, and the cortex of the shaft was thin (Fig. 18).

Case 16.—A white woman, aged 28, when 1 year old had an attack of acute anterior poliomyelitis which resulted in a complete permanent paralysis of all the muscles of the right leg and a partial paralysis of the thigh. The extensor muscles of the thigh were paralyzed. There was power in the hamstring muscles. There was marked muscle atrophy of the leg and less marked atrophy of the thigh. In spite of the extent of the paralysis, the patient had continu-

ously used the leg for walking. Roentgenograms of the bones of both lower extremities were studied. Considering the marked difference in muscles of the two legs, there was surprisingly little difference in the appearance of the bones of the two legs. The right tibia was slightly shorter and thinner. The cancellous bone was only slightly more porous. The diameter of the shaft was slightly decreased (Fig. 19).

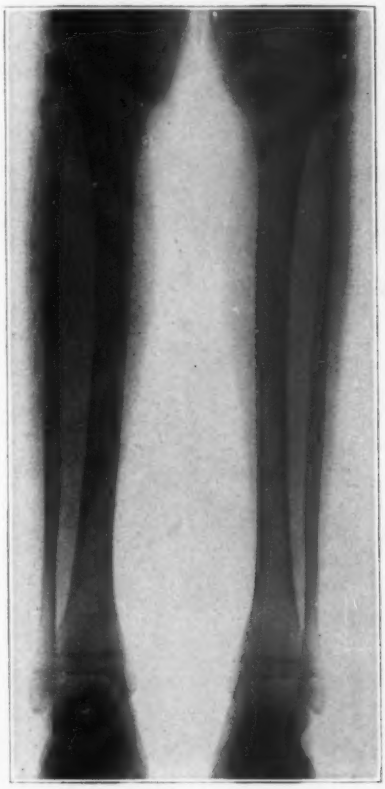

Figure 11

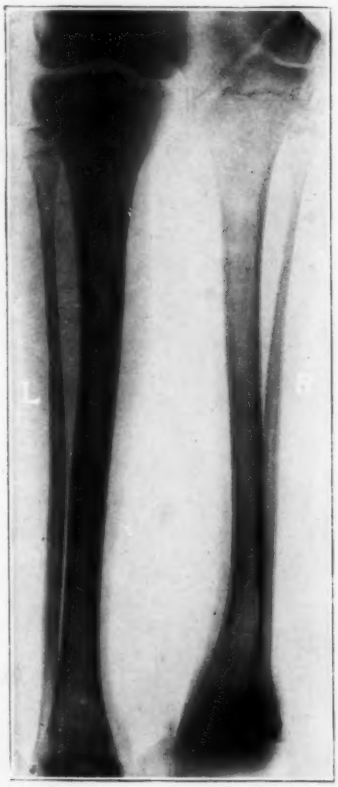

Figure 12

Fig. 11.—Roentgenogram of the bones of the legs in Case 11, a girl, aged 12 years, who did not use the right leg for a period of about eight months at the age of 6 years, owing to acute osteomyelitis of the distal end of the femur. The recovery from the disability was complete. The unmistakable evidences of lack of use during the growing period are seen in the abnormal shape and size of the bones of the right leg.

Fig. 12.—Roentgenogram of the bones of the legs in Case 12, a boy, aged 14 years, who had sustained repeated fractures of the right femur. These roentgenograms were made two months after the last fracture, at which time there was lack of union of the fragments due to malposition. The bones of the right leg show marked atrophic changes and growth disturbance. All epiphyseal cartilages are distinct, but they are thicker in the bones of the left leg. Compare with Figure 13.

III. RELATION BETWEEN CHANGES IN BONE AS A RESULT OF LACK OF USE AND THE CAUSE OF THE NONUSE

From the study of the changes in bones which followed lack of use from various causes in both children and adults, there was no evidence that the cause of the lack of use affected these changes in any manner. The same atrophic changes in bone were observed when the lack of use was due to anterior poliomyelitis, spastic paralysis, peripheral nerve injury, Friedreich's ataxia, pseudomuscular atrophy, syringo-

Figure 13

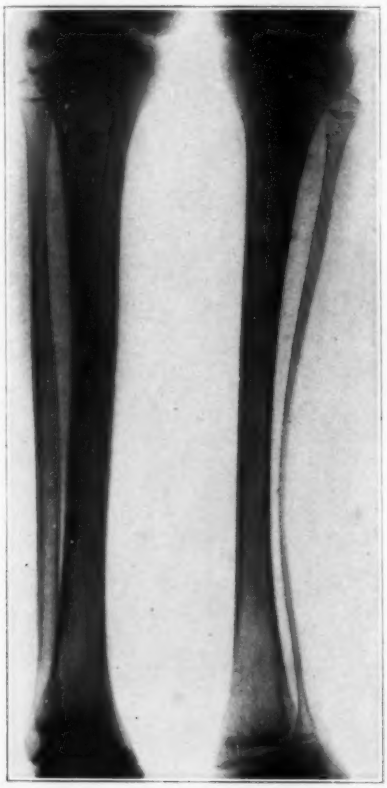

Figure 14

Fig. 13.—Roentgenogram of the bones of the legs in Case 12, after healing of the fracture of the femur and continuous use of the extremity for a period of about one year. The increase in thickness of the cortex of the shaft of the right tibia and the increased strength of the struts of the cancellous bone may be noted. The epiphyseal cartilages are absent in the bones of the right leg. Compare with the measurements recorded in the description of Case 12.

Fig. 14.—Roentgenogram of the bones of the legs in Case 13, a boy, aged 15 years, with a left congenital clubfoot. The bones of the left leg show the effects of incomplete function during the growing period. The fibula shows more change than the tibia on account of the position of the foot.

myelia, chronic arthritis, tuberculosis of bone, pyogenic osteomyelitis, contracture, fracture, congenital deformities and astasia abasia. The character of the changes was the same in all instances. The amount of the changes varied directly with the extent of the lack of use. There was absolutely no evidence that bone atrophy was ever the result of specific nerve influence on bone, and it is, therefore, unwarranted to assume that bone atrophy is ever a neurotrophic phenomenon. To emphasize this important point, Figures 7, 10, 12 and 17 show the changes in the tibias of children affected by anterior poliomyelitis, peripheral nerve injury, tuberculosis of the hip and fracture of the

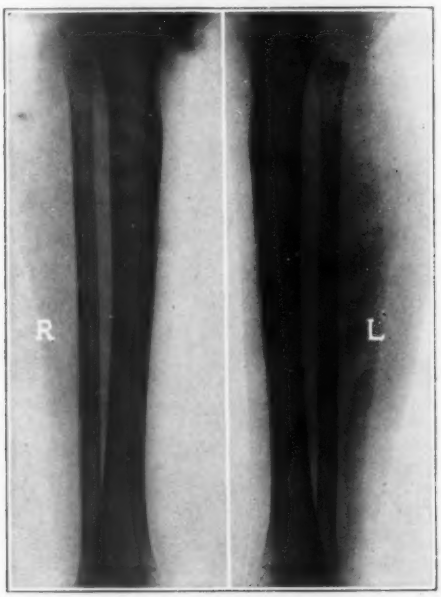

Fig. 15.—Roentgenogram of the bones of the legs in Case 14, one month after the onset of an attack of acute poliomyelitis. The bones of both legs appear normal.

femur, and Figures 1, 2, 3, 5 and 6 show the changes in the bones of adults which followed peripheral nerve injury, spastic paralysis, syringomyelia, fracture and infectious disease.

IV. CHARACTER OF CHANGES IN ADULTS

The initial atrophic changes in bone due to nonuse of an extremity are the same regardless of the age of the individuals. The ultimate result of the changes in the bones of an extremity which is not used is different in the person who has reached his complete growth from

that in the person who is in his growing period at the time of onset of nonuse. In the former instance, the process of bone atrophy is operating alone. In the latter, the process of bone atrophy is associated with the process of growth which is inhibited but not arrested by nonuse.

The changes in bone which result from lack of use during adult life are such that the general shape and contour of the bone as a

Fig. 16.—Roentgenogram of the bones of the legs in Case 14, made three months after those shown in Figure 15. The amount of atrophic change which has taken place may be noted.

whole are only slightly modified. The diameter of the shaft may be very slightly decreased. The length is not changed. The medullary canal is increased in diameter, producing a corresponding diminution in the thickness of the cortex, which after a long period of nonuse is reduced to a thin bone shell. The cancellous bone becomes much more porous, with fewer and thinner trabeculae. After a long period of nonuse, the compact bone of the shaft becomes porous. This

porosity explains the linear striae seen in the roentgenogram. Various degrees of bone atrophy due to nonuse during adult life are shown in Figures 1, 2, 3, 5 and 6.

V. CHARACTER OF CHANGES DURING PERIOD OF GROWTH

The changes in bone which result from lack of use during the growing period are of particular interest because two distinct processes are operating together, and the ultimate result is a marked change in the shape and contour of the whole bone. The bone is smaller both

Fig. 17.—Roentgenogram of the bones of the legs in Case 14, made fifteen months after those shown in Figure 15. The further progress of the atrophic changes may be noted. Compare the illustrations with the measurements recorded in the description of Case 14.

in length and thickness; the decrease in thickness is more noticeable than that in length. Furthermore, the diminution in thickness is more marked in the shaft than in the epiphysis, producing an effect of sudden enlargement at the epiphyseal regions. The thickness of the cortex relative to the diameter of the bone shows a change which is small compared with that seen in bone atrophy occurring during adult life. Comparative measurements of the thicknesses of the entire bones and

the diameters of the medullary canals show that the medullary canal of the nonused bone is always larger compared with the thickness of the same bone, although it may be actually smaller than the medullary canal of the corresponding bone of the used extremity. There may also be a difference in the shape of the cross section of the bones, comparing used with nonused; for example, the cross section of a normal used tibia is triangular in outline while the cross section of a tibia which has not been used during the growing period more nearly approaches a circle.

The various stages of the combined effect on bones of nonuse and growth are shown in Figures 17 and 18.

VI. EFFECT OF NONUSE ON GROWTH OF BONE

The effect of lack of use on the process of growth of bones deserves special comment. That growth in length and thickness of bones takes place in complete absence of any use whatever is generally known. It is also well recognized that lack of use of one extremity during the period of growth will result ultimately in a short extremity. Two causes of this phenomenon are possible. The bones may grow at a decreased rate, or growth may stop earlier in the nonused extremity. The distinction and relative importance of these two factors have not been appreciated.

From the study of the cases of nonuse during the period of growth, it is clear that lack of use of an extremity results both in inhibition of growth and in an abnormally early cessation of growth in bones.

For example, in a case of anterior poliomyelitis in which there was complete lack of use in one extremity from four to nine years, there was a difference of 1.5 cm. in the lengths of the tibias. In another case of poliomyelitis in which there was a complete unilateral lack of use from four to twenty-five years, there was a difference in the lengths of the tibias of 3.4 cm. In a case of fracture of the femur in which the disability extended from eight to fourteen years, the tibias measured 29.8 and 32.3 cm., a difference of 2.5 cm. At this time the epiphyseal cartilages were present in both tibias. The same patient was studied again at the age of 15, at which time the epiphyseal cartilage was absent in the atrophied tibia and present in the used tibia. The tibias at this time measured 29.9 cm. and 33.3 cm., a difference of 3.4 cm., the increase in difference during the ages of 14 and 15 being due almost entirely to a cessation of growth in the tibia of the nonused extremity and a continuation of growth in the tibia of the used extremity.

The effect of the lack of use during the period of growth on the contour of bones was typically shown in Case 14, in which the bones

of the leg were studied for a period of thirteen months from the beginning of the nonuse. Following the onset of the paralysis, the bones began to change in shape. The length increased. There was a continuous diminution in the diameter of the shaft. The diameters of the epiphyses continued to increase. The bone, therefore, in this period, changed in contour corresponding to that always found in bones of

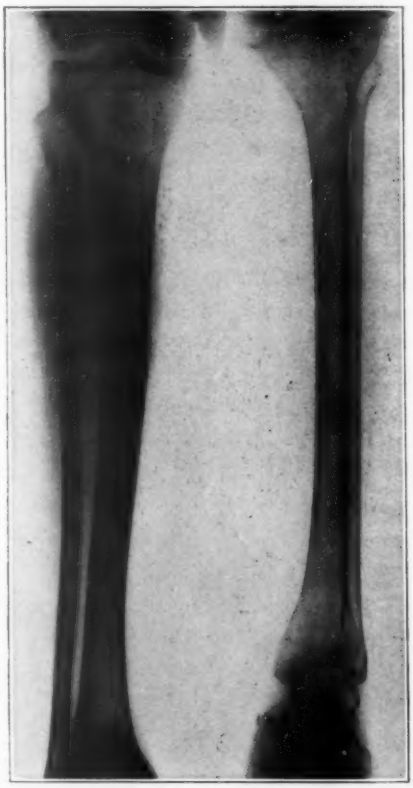

Fig. 18. — Roentgenogram of the bones of the legs in Case 15, a woman, aged 25, with complete paralysis of the left leg and partial paralysis of the left thigh as a result of an attack of acute poliomyelitis at the age of 4 years. The extremity had not been used. The marked changes in the bones of the left leg may be noted. Compare with Figure 19.

nonused extremities during the period of growth, namely, a small round shaft with relatively large flaring epiphyses (Figs. 14, 15, 16, 17 and 18).

VII. EFFECT OF NONUSE ON REGENERATION OF BONE

The effect of bone atrophy on regeneration of bone has been previously studied experimentally by us. It was found that bone atrophy

did not affect the process of bone regeneration. The proof of this conclusion has been confirmed by this clinical study. In Case 12, in which there was repeated fracture of the femur associated with extreme bone atrophy, each fracture united promptly when apposition of fragments was secured. In another case of extreme bone atrophy due to twelve years' lack of use of one lower extremity because of tabes dorsalis and a Charcot's hip joint, a fracture of the femur produced a large callus in four weeks.

VIII. RECOVERY FROM BONE ATROPHY

An appreciation of the marked changes in the bones of an extremity which result from the lack of use of this extremity naturally leads to a consideration of the character and quantity of changes which may follow a reestablishment of function in the extremity. For the study of the process of recovery from bone atrophy, two groups of cases have been used. One group consisted of cases in which the history made it practically certain that the bones had previously been in a marked state of atrophy from nonuse. In these cases the bones were studied in comparison with a previous state presumed to have existed from our experience in other cases. In a second group of cases the bones were studied during the actual period of reestablishment of use. A period of two years is relatively short for a study of the second group of cases.

In Case 16 there was an attack of acute poliomyelitis at the age of 1 year, which resulted in a complete permanent paralysis of all the muscles of the leg. The patient, however, learned to walk during childhood and continued to use the extremity until she was observed at the age of 28 years. There was certainly a period after the onset of the paralysis in which the bones of the paralyzed leg were markedly atrophic. The end-results of establishment of use of the extremity, however, was that there were only slight differences in size and contour of the tibia.

In Case 11 there was lack of use of one lower extremity for a period of about eight months at the age of 6 years and a subsequent apparent, complete restoration of function. The patient was studied at the age of 12 years. At this time there was a difference in the size and contour of the tibia. The disease process was a "mild" osteomyelitis of the distal end of the femur.

In Case 12 the effect of one year's continuous use of an extremity in which the bones were atrophic from lack of use were studied in a boy between 14 and 15 years of age. During this period there was a marked increase in the thickness of the cortex of the shaft. The diameter of the shaft increased and the diameter of the medullary canal decreased. The thickness of the individual trabeculae of the

cancellous bone increased. There was, however, no evidence of an increase in the number of trabeculae per unit of area. In a case of tuberculosis of the knee in a woman, aged 30, who had not used the left lower extremity since she was 17 years old, roentgenograms revealed marked atrophy of all the bones of the extremity. The left knee was fixed in a position of flexion at 45 degrees (Fig. 20). The knee

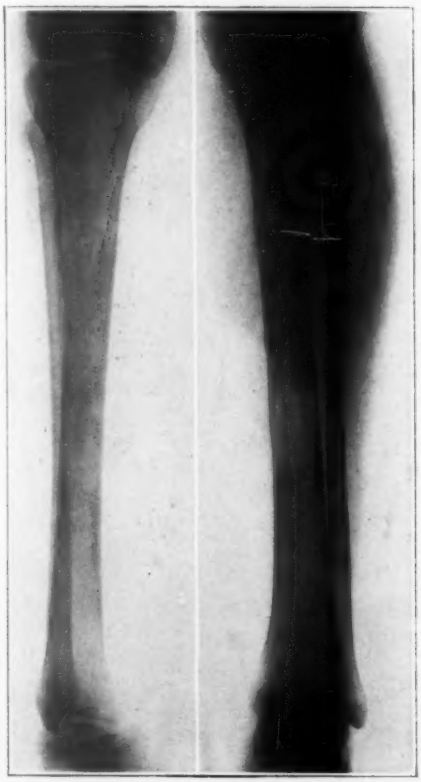

Fig. 19.—Roentgenogram of the bones of the legs in Case 16, a woman aged 28, with complete paralysis of the muscles of the right leg and a partial paralysis of the muscles of the right thigh as a result of an attack of acute poliomyelitis at the age of 1 year. The patient learned to use the extremity for walking, and it has been used continuously in spite of extensive paralysis. The bones of the right leg show atrophic changes, but these changes are much less marked than those found in Case 15, in which there was an equal amount of muscle paralysis but complete lack of use.

joint was excised and the patient was kept in a cast for a period of six months. Roentgen-ray examination revealed a further progress of the bone atrophy. The cast was removed and the patient began to use the extremity. Roentgen-ray examinations were then made at

intervals for a period of two years. During the last year the patient was walking on the leg with no other inconvenience than a stiff knee. After the reestablishment of a useful extremity there was a continuous change in the bones. The thickness of the cortex of the shafts of the bones increased to a marked degree. The trabeculae of the cancellous bone increased in thickness. There was, however, no evidence of the formation of new bone trabeculae (Fig. 21). The thickness of the

Fig. 20.—Roentgenogram of the knee of a woman, aged 30, showing marked atrophic changes associated with tuberculosis of the knee joint. Compare the thickness of the cortex of the femur and the appearance of the cancellous bone with that shown in Figure 21.

cortex of the shafts of the bones still remained much less than in the corresponding bones of the extremity which had been continuously used since birth.

From the study of these and other cases, therefore, certain conclusions may be drawn as to the recovery from bone atrophy. If the lack of use is during the period of growth, there will be permanent changes in the size and shape of the affected bones. The reestablish-

ment of use will not result in a sufficiently increased rate of growth to make up for the loss which has occurred during the period of nonuse. It is obvious that to bring this about it would be necessary for a rate of growth above normal to take place. If the lack of use is during the adult period, the shape and size of the bones are not materially changed, and the reestablishment of use results in only an increase in the thickness of the existing parts of the bone. It is partic-

Fig. 21.—Roentgenogram of the same knee shown in Figure 20, two years later, during which time the knee joint was resected and use of the extremity had been reestablished. The marked increase in thickness of the cortex of the femur and the increase in density of the trabeculae of the cancellous bone may be noted.

ularly interesting that lack of use results in a complete disappearance of part of the trabeculae of the cancellous bone. On reestablishment of use, these trabeculae are not reformed; but the existing trabeculae increase in thickness to a degree greater than normal. This results in the cancellous bone becoming a coarser network of struts of greater

thickness. It is, therefore, often possible from examination of roentgenograms of bones to detect unmistakable evidence of previous periods of lack of use and to predict with some degree of accuracy the period in the patient's life during which the extremity was not used. This statement is particularly applicable to instances in which the lack of use was unilateral.

The changes in bones resulting from lack of use and the recovery from the changes after the reestablishment of use have in all instances already referred to occurred as a result of diseases of the extremities. In a single instance in which a white woman, aged 48, was confined to bed for a period of one year incidental to repeated operations for intra-abdominal disease, it was found that all the bones of the extremities showed marked atrophy. The fact that bone atrophy occurs as a result of confinement in bed is a matter of considerable clinical interest, particularly as it concerns children. The material which has been studied has not been sufficient to permit drawing definite conclusions, except to state that long confinement results in atrophic changes in the bones.

IX. SUMMARY

It may be stated that these observations are evidence for the truth of a general theory of bone atrophy. Bone atrophy and recovery from bone atrophy are manifestations of the function of bone cells to produce bone matrix, which is in whole or in part distinct from the function of the bone cells to regenerate themselves. Bone atrophy and recovery from bone atrophy are processes which are not necessarily associated with cell death or cell proliferation. Regeneration is a process which is directly the result of cell multiplication.

EXPERIMENTAL STUDY OF THE HEALING OF FRACTURES *

LEONARD W. ELY, M.D.

SAN FRANCISCO

This study was undertaken to clear up several obscure points in the process of healing of fractures, but chiefly to ascertain the exact rôle assumed by the periosteum. Three sets of experiments were performed on cats, and in all the humerus was fractured.

In the first series, the humerus was fractured by direct external violence, applied laterally. I used my thumb as a fulcrum, and, in case the bone was too tough to be broken thus, I broke it over the edge of the table. In the second series, I made a lateral incision, dissected the tissues down to the periosteum, divided the periosteum circularly, fractured the bone with a Gigli saw or Liston bone forceps, and sutured the wound. The third series was similar to the second, except that the periosteum was simply slit longitudinally to give access to the bone.

Complete narcosis under ether was employed, and in the open operations due attention was given to asepsis. The cats were killed at intervals, Cats 16 and 17 with chloroform, the rest with illuminating gas.

The fractured bone, with its periosteum, was removed shortly after death, and was fixed in from 4 to 10 per cent. liquor formaldehydi, and was decalcified in a 5 per cent. solution of nitric acid. In the case of three cats (Cats 10, 11 and 12), the bones were placed immediately in nitric acid solution by mistake, without previous fixation. All but these three were roentgenographed before decalcification. Each specimen was divided longitudinally, was run up through the alcohols and ether, and was mounted in celloidin. Sections were cut and stained with hematoxylin and eosin, and with the Unna and van Gieson stains.

PROTOCOL OF EXPERIMENTS

FIRST SERIES: SIMPLE FRACTURE BY DIRECT VIOLENCE

EXPERIMENT 1.—Cat 1, a large sized, adult animal, was killed with illuminating gas, four days after the fracture. Marked ecchymosis was revealed when the cat was skinned. There was marked displacement of the fragments, with overriding. The bone was removed, together with the surrounding tissues, and was sectioned longitudinally. One half the specimen was decalcified, embedded, cut and stained.

The stained slide showed no overriding, but slight lateral displacement. The bones were situated end to end. The marrow canal of one was open, but the knife had caught the other bone obliquely so that its cortex shut off its canal on

* From the laboratory of surgical pathology, Stanford University.

the slide. In the tissues about the ends of both bones was much fibrin, and a mass of fibrin in which were one or two bone spicules separated the two. The surrounding tissues showed cellular infiltration.

Fragment with the Open Canal.—The lymphoid marrow appeared as a band on each side of the canal, plugging up the end, with the fatty marrow in the center. A layer of fibrin also lay partly across the end of the canal. The periosteum showed two distinct layers of about equal thickness, an inner, or cellular, and an outer, or fibrous layer. It ended a short distance from the fractured extremity, leaving the cortex bare. The outside of the cortex on one side was irregular and notched, and showed an irregularity of staining reaction, as if it were already being attacked, and it looked as if the formation of Howship's lacunae were beginning, but no giant cell osteoclasts were in evidence. This observation, if correctly made, would indicate that the so-called osteoclasts were not the cause of the osteoclasis, but the result.

Fragment with the Closed End.—This contained lymphoid marrow. The cortex was covered with periosteum in two distinct layers, the inner increasing markedly in thickness toward the end of the bone. The marrow canal contained many bone trabeculae.

Summary.—The ends of the fragments were buried in fibrin. There was an aggregation of lymphoid marrow at the circumference of the marrow canal of one fragment. The periosteum lay in two distinct layers.

EXPERIMENT 2.—Cat 2, a full grown cat, was killed with illuminating gas, eight days after the fracture. There was no sign of epiphyseal cartilage in the head of the humerus. Less ecchymosis was present than in the first cat, and that only about the elbow and fore leg. There was much overriding of the fragments. The bone was removed with the surrounding tissue.

Two sets of slides were made. Each set showed one bone cut longitudinally, with its marrow canal open on the end, and the other cut diagonally, with its marrow canal closed by bone. Evidently, each fragment was cut fairly in one set of slides. One of the fragments showed splintering. The two fragments overlapped. Remains of hemorrhage were present at their ends. The ends were surrounded by granulation tissue, and this granulation tissue ran for a very short distance into the marrow canal as if to plug it up. The tips of the cortex showed well marked so-called rarefying osteitis.

The behavior of the periosteum was peculiar. At some distance from the fracture, it left the bone, the space between the two gradually widening, and showing distinct evidence of new bone trabeculae. The periosteum of one of the fragments was notable because of the presence in it, or in its immediate vicinity, of well marked hemorrhage. This line of hemorrhage made the course of the periosteum more distinct. It was not diffuse, but followed the periosteum closely. At a short distance from the broken end, the fibers of the periosteum diverged from one another, and, just before the end of the bone was reached, they were lost in the granulation tissue. No bone trabeculae appeared within the cortex.

The foregoing holds good for one fragment—the clean cut one. The splintered fragment showed a rather different picture. The periosteum was not so easily recognized, and no bone trabeculae appeared under it, *except at some distance from the end.* New bone trabeculae were abundant on the inside of the cortex.

Summary.—Granulation tissue surrounded the bone ends. There was beginning bone formation on the outside of the cortex of one fragment and on the inside of the cortex of the other.

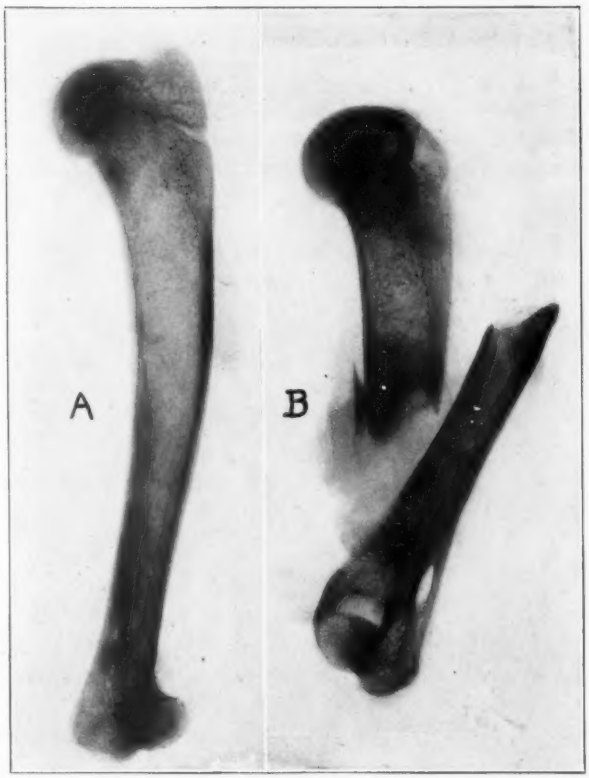

Fig. 1.—*A*, normal humerus of Cat 1; *B*, fractured humerus of Cat 1 after removal.

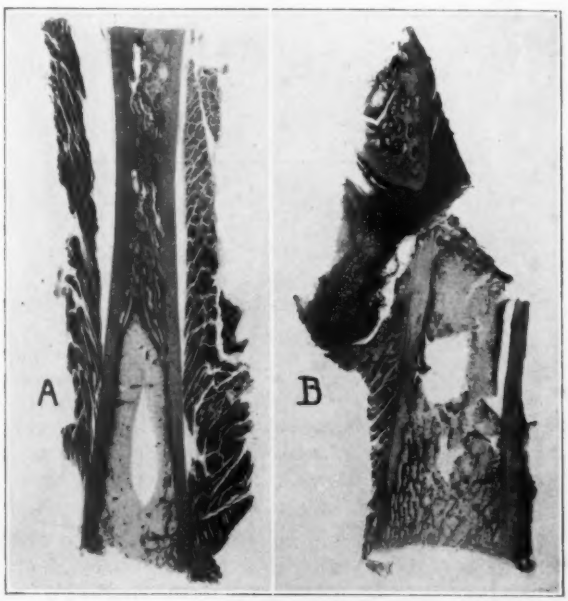

Fig. 2.— *A*, stained slide cut from normal humerus of Cat 1; *B*, stained slide cut from fractured humerus of Cat 1.

EXPERIMENT 3.—Cat 3 was killed with illuminating gas, thirteen days after the fracture. There was no ecchymosis. Thickening was present about the seat of fracture, but apparently there was less overriding than in Cats 1 and 2. There was free motion. The bone was removed with the surrounding tissue, and sectioned longitudinally.

One of the bones had been caught by the knife in such a way that it appeared as a small point of bone slightly overlapping the irregular fractured end of the other fragment. The two fragments were bound together by a mass of fibrous tissue and cartilage; and in this fibrous and cartilaginous tissue, the formation of bone trabeculae was well advanced. Small spicules of bone, evidently fractured at the time of operation, could be seen here and there. The new trabeculae were especially abundant on the outside of the cortex, immediately beneath the periosteum. They capped the pointed fragment,

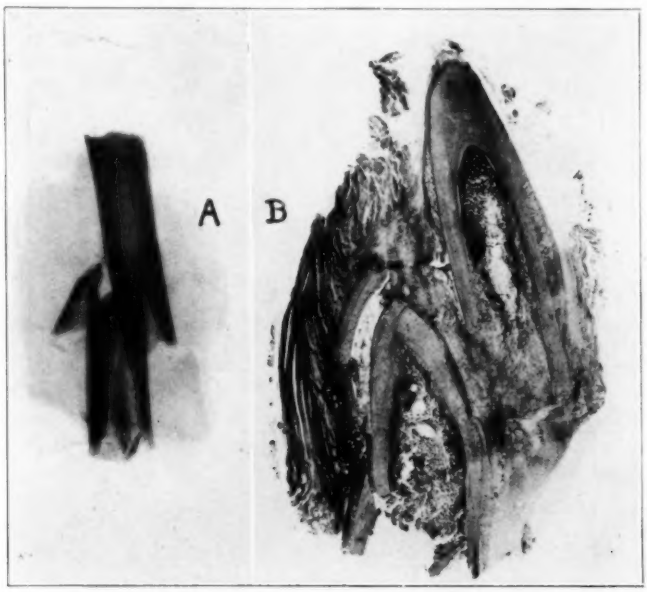

Fig. 3.—*A*, fractured humerus of Cat 2; *B*, stained slide cut from fractured humerus of Cat 2.

and, on the other fragment, they were especially numerous on the far side of the cortex. In the latter fragment the formation of internal callus was beginning, not on the inner aspect of the cortex but in the marrow canal itself. One small fractured spicule of bone showed the formation of new trabeculae on its borders.

Summary.—The fragments were bound together by fibrous and fibrocartilaginous tissue, in which new bone was forming. New trabeculae were especially numerous on the outside of the cortex. There was some new bone formation within the canal of one fragment—so-called internal callus.

EXPERIMENT 4.—Cat 4 was killed with illuminating gas, sixteen days after fracture. There were slight remains of ecchymosis, thickening about the seat of fracture and marked overriding. The bone was removed with the surrounding tissue, and sectioned longitudinally.

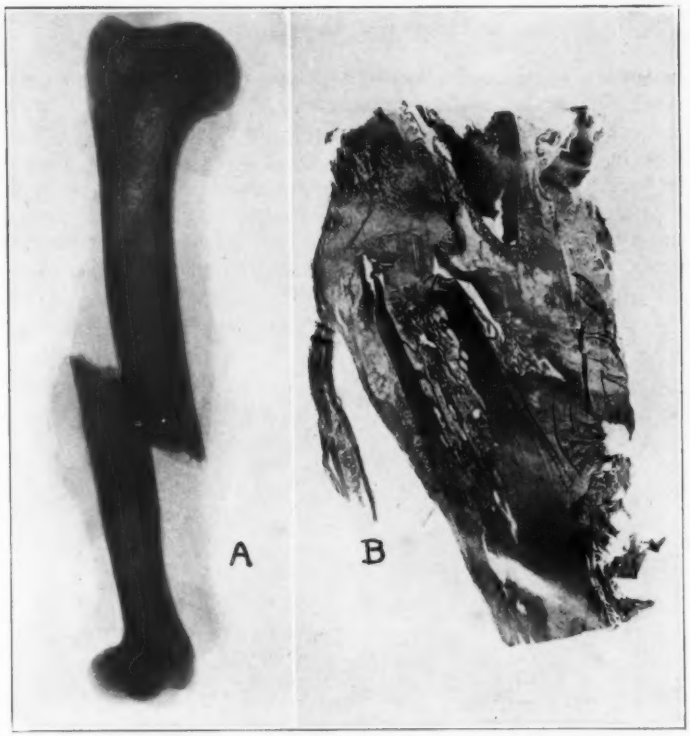

Fig. 4.—*A*, fractured humerus of Cat 3; *B*, stained slide cut from fractured humerus of Cat 3.

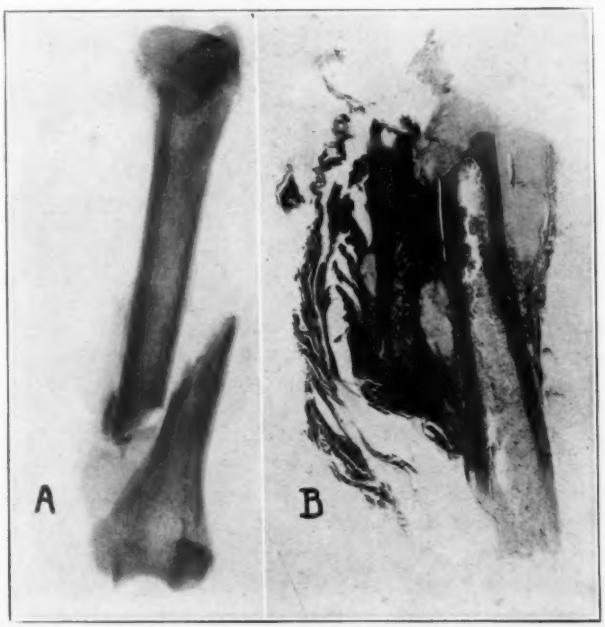

Fig. 5.—*A*, fractured humerus of Cat 4; *B*, stained slide cut from fractured humerus of Cat 4.

Examination of Stained Slide.—The knife had caught one fragment fairly, but the other fragment evidently was split. The two fragments had overriden about 1.5 cm. Dense bone almost shut off the marrow canal of the fragment caught fairly. This was evidently due to diagonal sectioning, because it was not new bone. At the end of each fragment was a mass of fibrous tissue containing rifts. Almost capping one fragment and extending well over on its far cortex was a large mass of cartilage. A much smaller area appeared on its near cortex, about a centimeter from its fractured end, and a still smaller piece on the outside of the far cortex of the other fragment, about 0.5 cm. from its fractured end. Cartilage and fibrous tissue thus united the two fragments fairly firmly.

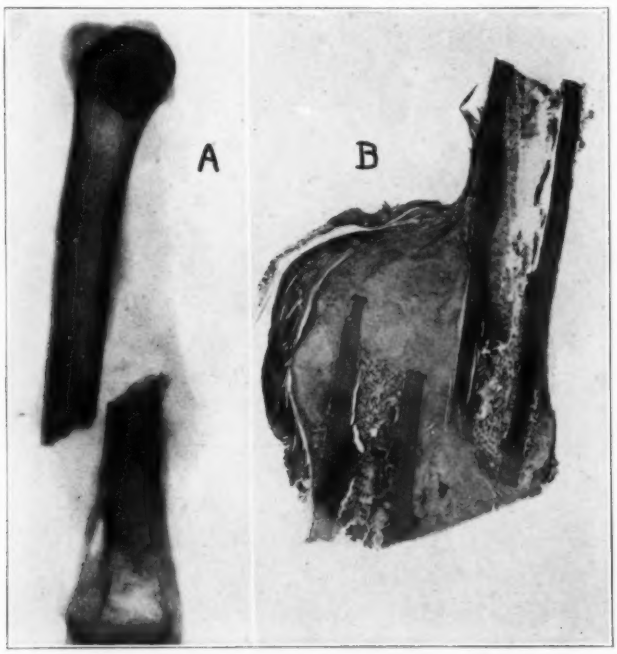

Fig. 6.—*A*, fractured humerus of Cat 5; *B*, stained slide cut from fractured humerus of Cat 5.

New bone trabeculae were forming on the outside of the cortex of both fragments, springing from it, as it were, not only in the masses of cartilage but also in and under the periosteum. Bone trabeculae were also forming on the inside of the cortex—internal callus.

Summary.—The fractured bones were united by cartilage and fibrous tissue, in which new bone trabeculae were forming. There were indications of internal callus in the marrow canals of both fragments, but this internal callus apparently played no effective part in the union.

EXPERIMENT 5.—Cat 5 was killed with illuminating gas, twenty days after fracture. There was considerable thickening at the seat of fracture with a little motion.

Examination of the Stained Slide.—The two fragments, overlapping about 6 or 8 mm. and separated by an interval of about 3 mm., were bound together

by a fusiform mass of fibrous tissue containing large and small islands of cartilage. Close to the bone cortex in places, ossification was beginning in this mass of new tissue, only to a minimal extent on one of the two apposed cortices, but to a much greater extent on the outside of the far cortex of each fragment. In the latter situation, intracartilaginous bone formation between the cortex and the periosteum was active and well advanced. New bone trabeculae were abundant in the marrow canal of each fragment in the neighborhood of its fractured extremity—the so-called internal callus. Continuous with the end of one cortex only new bone was being built up, apparently out of the fibrous tissue which embedded the end of the fragment. There were small rifts in the welding fibrous tissue.

Summary.—The overlapping bones ended in a mass of fibrous tissue and cartilage, which surrounded them like a plumber's wiped joint. New bone was

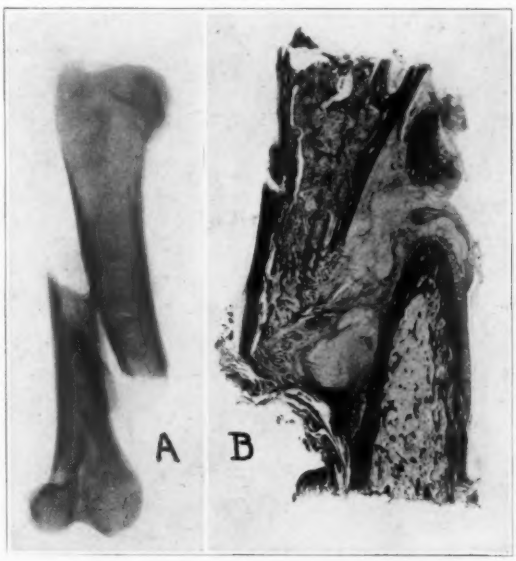

Fig. 7.—*A*, fractured humerus of Cat 6; *B*, stained slide cut from fractured humerus of Cat 6.

being built up in this fibrous tissue and cartilage. Internal callus was present in each marrow canal, but seemed to play no essential part in the process of healing.

EXPERIMENT 6.—Cat 6, a small, apparently young cat, was killed with illuminating gas, twenty-four days after fracture. The fragments showed marked overriding, and had no stability.

Examination of the Stained Slide.—The fragments overrode about 1 cm. The end of one fragment was open; the end of the other was closed off by bone, evidently the bone of the old cortex caught by the knife at an oblique angle. Between the two fragments lay a mass of cartilage, fibrocartilage and fibrous tissue. Fibrous tissue lay over the open end of one fragment, a cap of cartilage over the closed end of the other. In these two situations, new bone formation was beginning. It was also beginning in the cartilage in the angle where the periosteum left the cortex of one fragment to pass across to that

of the other, and externally on the cortex on the far side of one fragment. No indication of internal callus was present. A small fragment of bone lay at a short distance from the end of the closed fragment. It was probably part of a splinter. *On it new bone was being formed.* A large cleft or series of clefts ran from the end of one fragment, part way over to the other fragment in the fibrous tissue between the two bones.

Summary.—The bones were united by fibrous tissue containing masses of cartilage, especially in the immediate vicinity of the cortices. The marked instability, together with the presence of the rifts in the fibrous tissue, indicated that perhaps a false joint was in process of formation.

EXPERIMENT 7.—Cat 7, a small, probably young animal, was killed with illuminating gas, twenty-eight days after the fracture. There were marked overriding of the fragments and free motion.

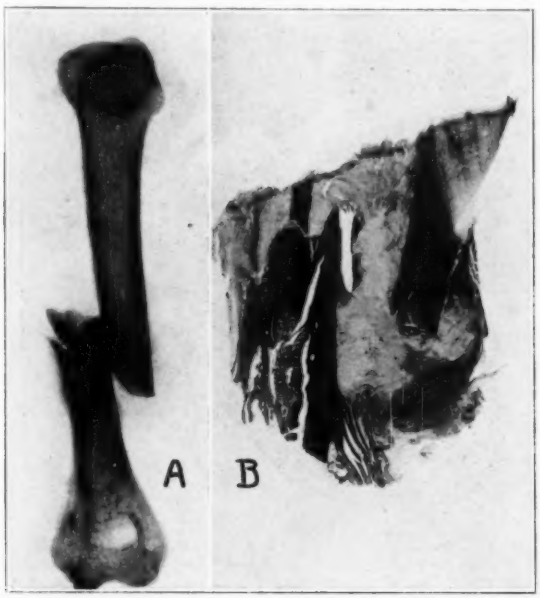

Fig. 8.—*A*, fractured humerus of Cat 7; *B*, stained slide cut from fractured humerus of Cat 7.

Examination of the Stained Slide.—The overlapping fragments were bound together by a dense mass of fibrous tissue and fibrocartilage which extended well over the end of each fragment. Hyaline cartilage was also present in this mass, especially near the cortex. The end of one fragment was comminuted. In this hyaline cartilage, close to the cortex, bone formation had begun, not only on the two cortices facing each other, but also to a lesser extent on the cortex on the far side. A few new trabeculae were visible in the marrow, here also apparently being formed from cartilage and fibrocartilage—the so-called internal callus. The new bone on the outside of the far cortex was forming under the fibrous periosteum in a sort of spindle shaped callus.

Summary.—There was cartilaginous callus, with bone formation beginning close to the cortex.

EXPERIMENT 8.—Cat 8, a very large, full grown cat, was killed with illuminating gas, thirty-five days after fracture. Considerable overriding of the fragments was present, and a little motion. Union seemed to be well advanced.

Examination of the Stained Slide.—The overriding of the fragments amounted to about 1.5 cm. The marrow canal of one fragment was open, that of the other was closed off by bone; but whether this was new bone or the old cortex cut obliquely it is impossible to say. A mass of cartilage lay between the two overriding fragments, and over the end of them. This cartilage was being ossified from each cortex. The ossification had proceeded to such an extent that fairly well formed marrow lay among the new trabeculae. Considerable internal callus was seen in the open ended fragment which appeared to

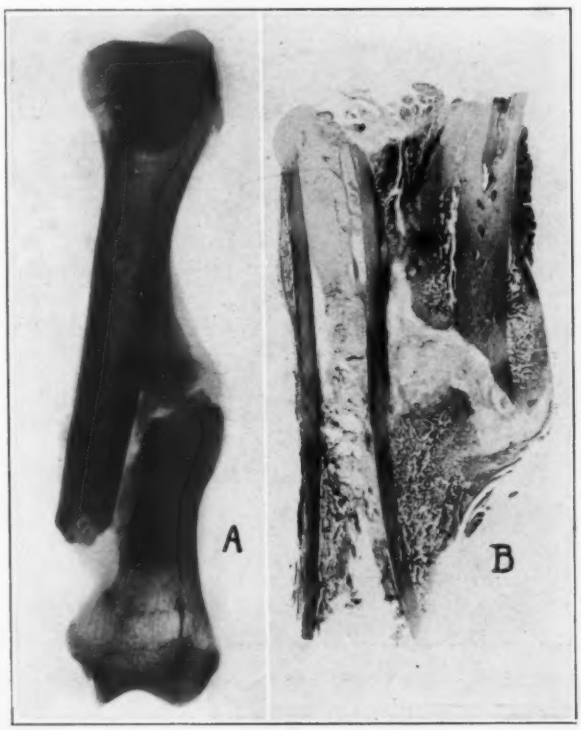

Fig. 9.—*A*, fractured humerus of Cat 8; *B*, stained slide cut from fractured humerus of Cat 8.

have no connection with the external callus. No evidence appeared of any effort at remodeling the fragments, except in the closed off end of one, where new blood vessels apparently were pushing into the bone, and causing an absorption, but without any evidence of so-called rarefying osteitis.

The periosteum had suffered in the cutting, but it could be fairly well traced from the far side of the cortex of one fragment, covering the new bone in that situation, and then across the new cartilage and bone formation almost to the other fragment. The periosteum on the far side of the other cortex was practically without reaction and ended shortly after leaving the bone, from which it had been stripped for about a centimeter. This was probably due to the cutting of the block.

Summary.—The fragments were fairly firmly welded together by a cartilaginous callus in which bone formation was well advanced. The periosteum did not appear to play any active part in the union.

EXPERIMENT 9.—Cat 9, a large, full grown animal, was killed with illuminating gas, forty-two days after the fracture. There was thickening about the seat of the fracture, and apparently firm bony union.

Examination of Stained Slide.—The two fragments, overriding about 1 cm., were closed off at their ends by old bone. This closure was evidently due to the obliquity of the cutting knife. They were united by a mass of cartilage, in which new bone formation was fairly well advanced and over which periosteum stretched. Bone formation was especially noticeable close to the cortex

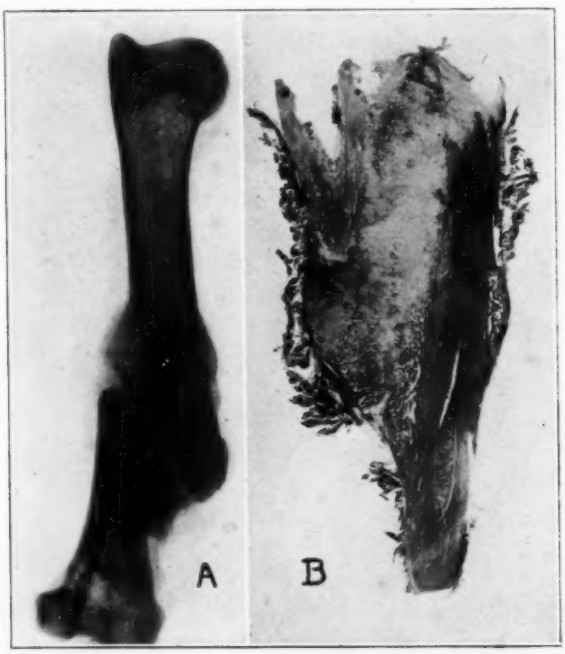

Fig. 10.—*A*, fractured humerus of Cat 9; *B*, stained slide cut from fractured humerus of Cat 9.

in the angle where the stripped-up periosteum left it to pass over to the other bone, but the periosteum itself was apparently not taking any active part in the bone formation. The mass of ossifying cartilage extended over the tips of the fragments. No evidence of any internal callus was seen.

Summary.—The overriding fragments were firmly welded by a mass of cartilage well advanced in ossification. The periosteum did not seem to be taking any part in the process.

EXPERIMENT 10.—Cat 10, an adult animal, was killed with illuminating gas, forty-nine days after fracture. Marked lateral displacement was present, and more than a centimeter of overriding. One sharp fragment seemed to have punctured the periosteum. The fragments moved a little on each other.

NOTE: Instead of being put in liquor formaldehydi, the specimen was put in 5 per cent. nitric acid immediately, by mistake, and remained in it for four weeks.

Examination of Stained Slide.—The fragments overrode to the extent of about 1.5 cm. The end of each was closed off by dense fibrous tissue, underneath which was a rather thin layer of newly formed bone. In the fibrous tissue were rifts. In the central marrow canal of one bone and on the inner aspect of the cortex of the other, new trabeculae were present—an indication of internal callus.

The two fragments were bound together by a dense tissue, part of which was fibrous, and the rest looked like cartilage under low power magnification, but contained no cartilage cells that could be distinguished. New bone trabeculae were being formed in this tissue at its junction with the cortex.

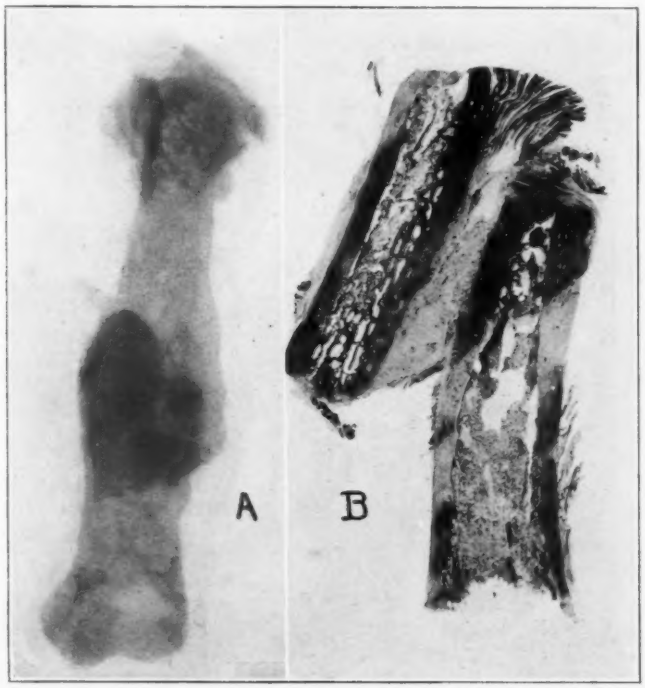

Fig. 11.—*A*, fractured humerus of Cat 10, subsequent to decalcification; *B*, stained slide cut from fractured humerus of Cat 10.

Summary.—There was fibrous and cartilaginous callus in which bone formation was advancing. The state of the specimen precluded arriving at finer details.

EXPERIMENT 11.—Cat 11, a small animal but apparently an adult, was killed with illuminating gas, fifty-seven days after the fracture. There was marked deformity at the seat of the fracture but apparently solid bony union.

NOTE: Instead of being put into liquor formaldehydi, the specimen was put into 5 per cent. nitric acid by mistake and remained in it for three weeks.

Examination of Stained Slide.—The ends of both fragments were pointed, bone shutting off their marrow canals, but this was probably an artefact, caused by the angle of the microtome knife. They were welded together by a fusiform mass of cartilage well advanced in ossification. The fragments themselves were separated by an interval of about 0.5 cm. Over the fusiform mass the peri-

osteum stretched. The new bone was especially abundant in the immediate vicinity of the cortex, and ossification was also well advanced in the angle where the periosteum left the bone at a short distance from its end, but the periosteum itself did not appear to be taking any active part in the new bone formation. In the cartilage, blood vessels could be seen, giving a picture analogous to that seen in an epiphysis when ossification is taking place. The mass of bone and cartilage lay between the bones, as well as about their ends. There was no indication of any internal callus.

Summary.—Firm union had been accomplished by ossification of cartilaginous callus. In this union the periosteum appeared to be taking no active part.

EXPERIMENT 12.—Cat 12, a very large animal, was killed with illuminating gas, sixty-three days after the fracture. Considerable deformity was present at the seat of fracture, with solid union.

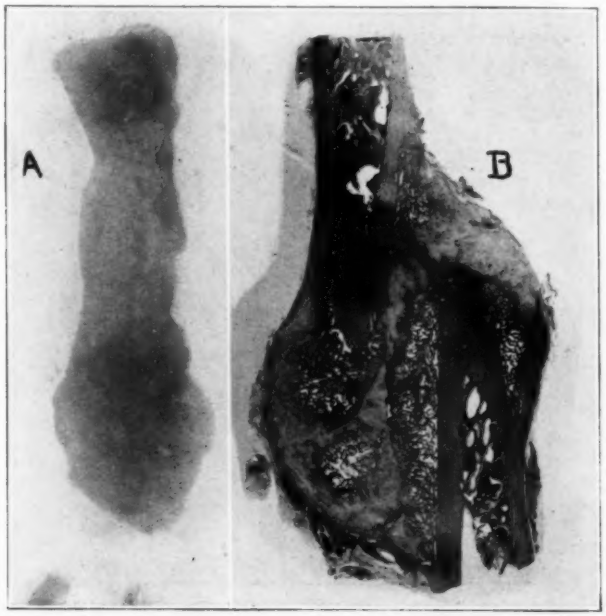

Fig. 12.—*A*, fractured humerus of Cat 11, subsequent to decalcification; *B*, stained slide cut from fractured humerus of Cat 11.

NOTE: Like the two preceding, this specimen also was put into 5 per cent. nitric acid immediately, by mistake, and remained in it for three weeks.

Examination of Stained Slide.—The two fragments overlapped for about 2 cm. The end of one had been caught obliquely by the microtome knife so that the cortex appeared to close the end of the central marrow canal. The marrow canal of the other fragment had been closed off by new bone.

The ends of the fragments, not in close apposition, were united by new bone and by partly ossified cartilage, and the cortex of each fragment contiguous to this uniting tissue was opening up, that is, was being converted into spongy bone, so that evidently the marrow canals of the two fragments already communicated through the bone meshwork. No evidences of so-called

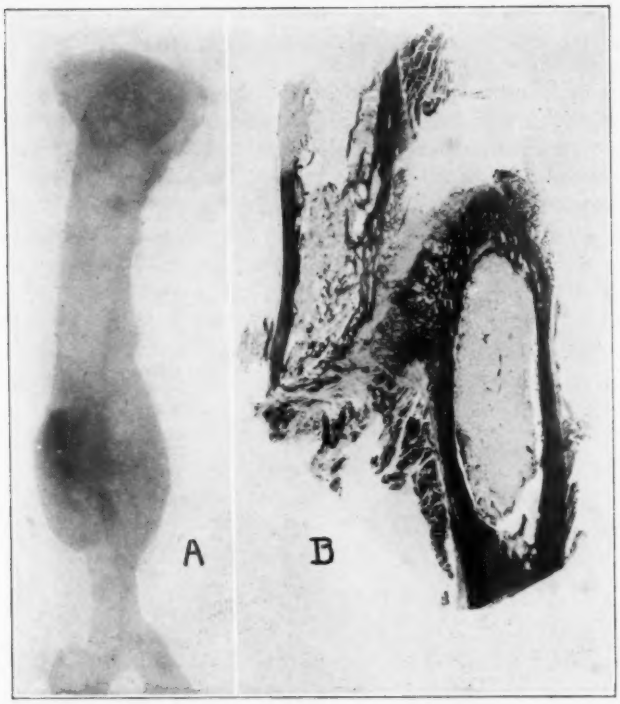

Fig. 13.—*A*, fractured humerus of Cat 12, subsequent to decalcification; *B*, stained slide cut from fractured humerus of Cat 12.

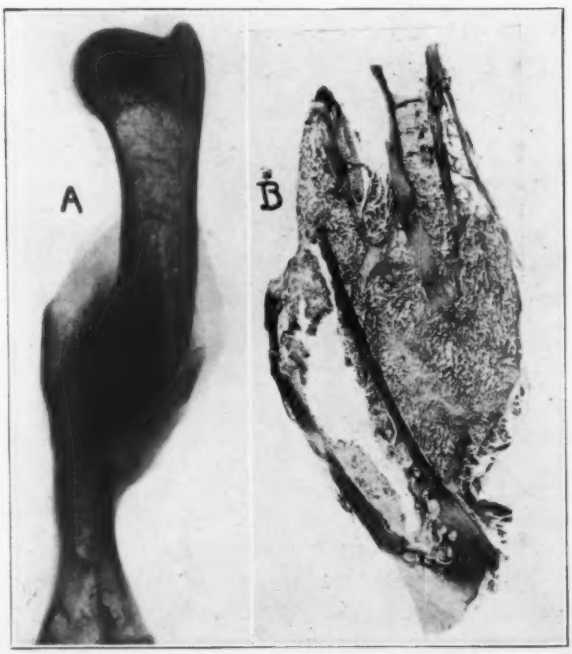

Fig. 14.—*A*, fractured humerus of Cat 13; *B*, stained slide cut from fractured humerus of Cat 13.

rarefying osteitis were present, however. In the immediate vicinity of this part of the cortex, the marrow canal of one fragment showed the new bone trabeculae of the internal callus, but not the marrow canal of the other. All about the closed end of the other fragment, bone trabeculae were forming in fibrous tissue.

Summary.—New bone from cartilage and fibrous tissue united the fragments laterally. There was rearrangement of the bony architecture. The rôle of internal callus was insignificant. The rôle of the periosteum was hard to distinguish.

EXPERIMENT 13.—Cat 13, a large animal, was killed with illuminating gas, seventy-one days after the fracture. Marked thickening was present at the site of fracture, with overriding and firm bony union.

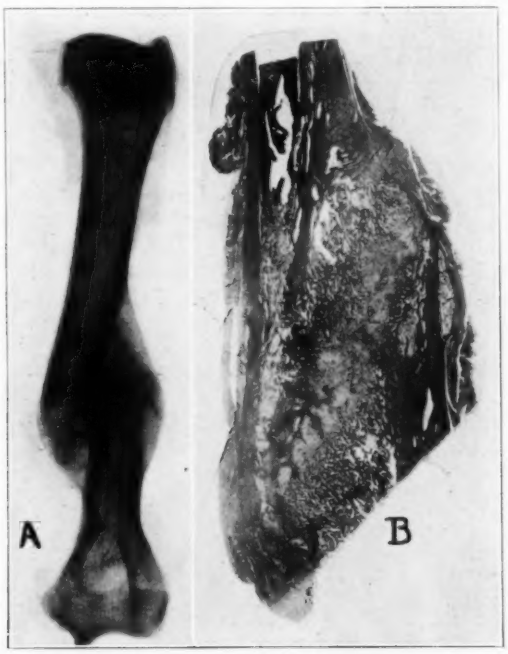

Fig. 15.—*A*, fractured humerus of Cat 14; *B*, stained slide cut from fractured humerus of Cat 14.

Examination of Stained Slide.—The fragments overrode for about 0.5 cm. and were separated laterally about the same amount. They were united laterally by a mass of newly formed bone, some of which was not yet completely ossified. No cartilage could be detected in this bone. The new bone covered the end of each fragment like a cap, and apparently its blood vessels communicated with those in the marrow canals in the fragments.

Summary.—New bone united the overlapping fragments laterally.

EXPERIMENT 14.—Cat 14, a rather small animal, was killed with illuminating gas, seventy-seven days after the fracture. There was overriding of the bone ends, with firm union.

Examination of Stained Slide.—The two fragments, overlapping for about a centimeter, had been firmly united by a mass of bone developed from cartilage, laid down between their overlapping cortices. The bone development was not yet completed, because a large amount of cartilage was still mixed up with the bone tissue, and rearrangement of the bone trabeculae was still progressing. Owing to the fact that one fragment had been caught obliquely by the microtome knife, its architecture could not be well made out; but study of the end of the other fragment demonstrated that the end of the cortex facing the first fragment had been torn down, and that spongy and irregular bone had replaced it, showing that its presence was no longer necessary. The cortex on the far side near its end had suffered slightly, and in one limited area was being replaced

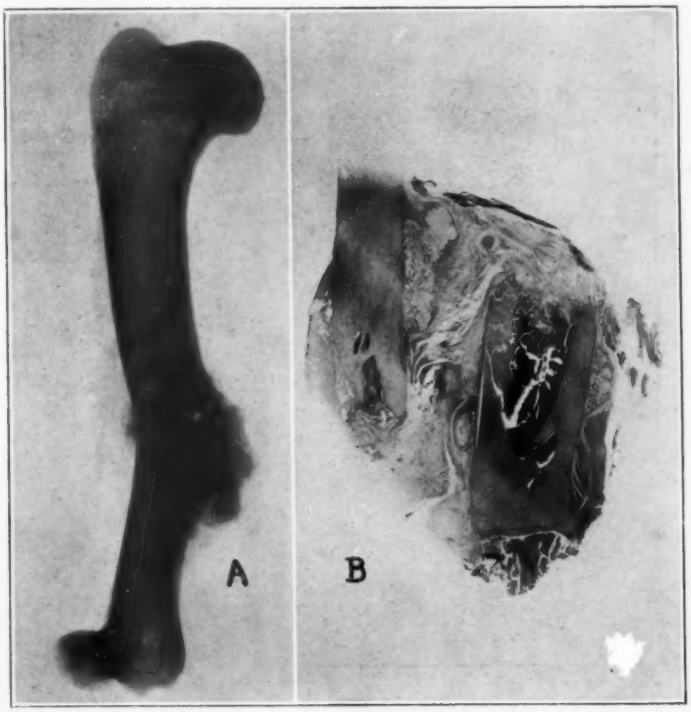

Fig. 16.—*A*, fractured humerus of Cat 15; *B*, stained slide cut from fractured humerus of Cat 15.

by spongy bone. In this exact place new bone had been built up beneath the periosteum on the outside of the cortex.

Summary.—The overlapping ends of the fragments were united firmly by new bone, chiefly developed from cartilage. The architecture of the cortex was being rearranged.

SECOND SERIES

With Cat 15 begins a new series of operations. An incision was made on the lateral aspect of the fore leg and the dissection was carried to the periosteum. This was divided circularly, and the bone

was fractured either with a Gigli saw or Liston bone forceps. The wound was then sutured, and a sterile dressing was applied. Infection occurred only once in the series.

EXPERIMENT 15.—Cat 15, a large, full grown animal, was killed with illuminating gas sixty-five days after the fracture. An incision had been made down to the bone; also an attempt, not very successful, had been made to divide the periosteum. The bone had been fractured with Liston bone forceps. Deep and superficial sutures had been made and collodion applied.

Free motion was present at the seat of fracture, with overriding. There was no sign of union.

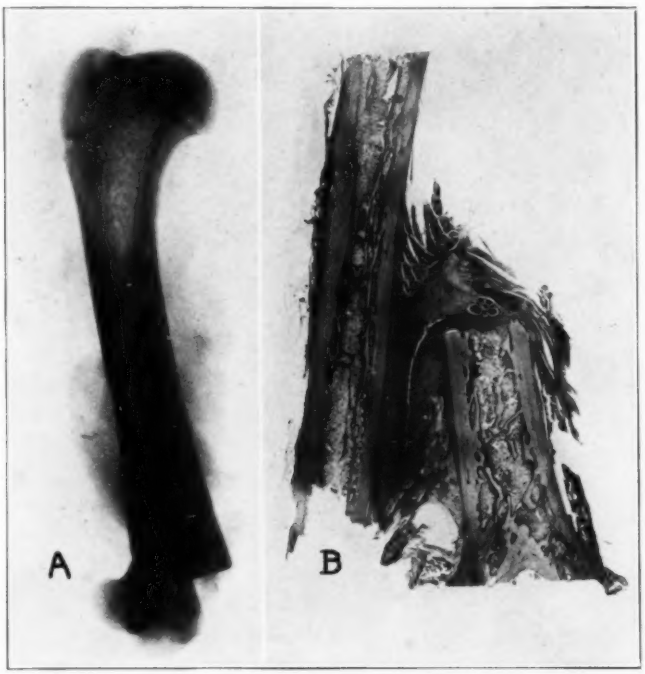

Fig. 17.—*A*, fractured humerus of Cat 16; *B*, stained slide cut from fractured humerus of Cat 16.

Examination of Stained Slide.—The specimen had been caught at an unsatisfactory angle by the microtome knife. One fragment showed its medullary canal, and in this canal new bone trabeculae could be seen. The other fragment showed the central medullary canal only at its extreme end, and here the new bone trabeculae were so abundant that they practically shut off the end of the canal. At the end of one cortex of the latter fragment, a cap of new bone was being formed out of cartilage. Each fragment showed new intracartilaginous bone formation, generally in irregular knobby areas on the outside of each cortex, but there was no bridge of bone and cartilage connecting the two fragments. On the outside of the cortex, the regular strips of new periosteal bone were missing, which were evident in the first series of operations. Irregular fibrous tissue covered the end of each fragment and bound the two

fragments together; but, except immediately contiguous to the cortex, no new bone or cartilage could be discerned in this fibrous tissue. Through this connecting tissue and running across diagonally from bone to bone was a large cleft, or, better expressed, a series of clefts. The walls of this cleft were irregular and in places showed well marked villous appearance, but no definite cartilage.

Summary.—There was formation of a false joint. The bones were united by fibrous tissue, and in this fibrous tissue was a series of rifts.

EXPERIMENT 16.—Cat 16, a large adult cat, was killed with chloroform, eleven days after the fracture. An incision was made as in Cat 15. Dissection was carried down almost to the bone. An aneurysm needle was passed about the bone, including some muscle tissue and the periosteum. A Gigli saw passed in the track of the aneurysm needle divided the bone and periosteum.

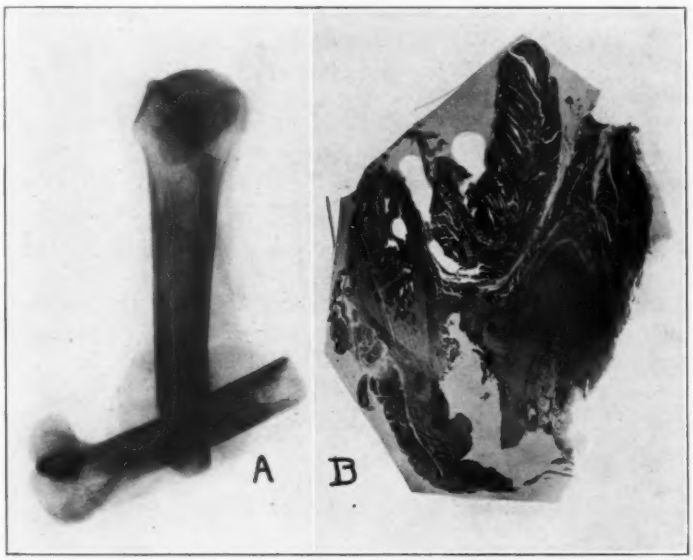

Fig. 18.—*A,* fractured humerus of Cat 17; *B,* stained slide cut from fractured humerus of Cat 17.

The wound became infected, and the cat was killed. The old wound was opened, revealing a large subcutaneous pocket of pus. Whether or not this pus pocket communicated with the fracture was not determined. The fragments had overridden noticeably. The distal end of the proximal fragment was down almost level with the condyles. The fragments moved freely on one another, and showed no sign of union.

The bones were removed, together with the surrounding tissues, were washed and then put into liquor formaldehydi.

Examination of Stained Slide.—The ends of the bones overlapped about 1.5 cm., and were bound together by a dense hyaline, fibrous tissue which appeared to be metamorphosing into cartilage, although no distinct cartilage cells could be seen in it. The marrow canals of both fragments were open. That of one fragment was closed off by the hyaline, fibrous tissue; but as to the other canal nothing could be said, for everything had been cut by the

knife, down to the end of the bone. In the fibrous tissue, and running almost parallel with the bones but slightly obliquely, was a distinct rift, as if a joint were being established. In the fibrous tissue on the apposed cortices, new bone formation was beginning, but on the cortices on the far side, no new bone was present, nor was there any evidence of the formation of an internal callus.

Summary.—There was probable infection. Apparently a false joint was in the process of formation.

EXPERIMENT 17.—Cat 17 was killed with chloroform, fifteen days after the fracture. The operation was the same as that performed on Cat 16 except that the saw broke during the operation, and the division of the bone was completed with Liston bone forceps.

The wound broke down and suppurated, necessitating chloroforming the cat after fifteen days. The bones were removed, with the surrounding tissue. They had overridden, and the distal end of the proximal fragment was at about the level of the condyles. There was no sign of union, and very free motion.

Examination of Stained Slide.—Both fragments had been caught at an angle by the microtome knife, so that exact details were hard to determine, but no union had taken place, and apparently the only effort at it was represented by a small amount of external callus on each cortex of each bone. There was an open space between the fragments lined by a tissue that had very much the appearance of synovial membrane.

Summary.—Suppuration was present, and there was practically no attempt at union.

EXPERIMENT 18.—Cat 18 was killed forty-five days after the fracture. There was circular division of the periosteum as with Cat 16, with division of the bone by a Gigli saw. When the cat was killed, the fragments were apparently firmly united in the presence of much callus.

Examination of Stained Slide.—The two fragments overlapped about 1.5 cm. They were about 1 cm. apart laterally, and their marrow canals were closed off by a very thin layer of new bone. This thin layer of bone was evidently being thickened up, for further intracartilaginous bone development could be seen going on outside of it. One fragment showed a few scattered trabeculae in its medullary canal, but neither fragment showed any internal callus in the shape of new bone on the inside of the cortex. There was practically no bone formation on the far side of the external aspect of either cortex. The two fragments, about a centimeter apart, were joined by a dense mass of new bone and cartilage, that is, by cartilage in which new bone formation was well advanced in the vicinity of the cortices, unossified cartilage separating the two strips of newly formed bone. Dividing this strip of cartilage through its whole extent, and running parallel to the bone, was an irregular but well defined slit or rift. This rift, bounded as it was by cartilage backed up by bone, and with its extreme ends closed off, gave an appearance strikingly analogous to that of a regular joint.

Summary.—There was formation of a new joint by means of a rift in the cartilaginous callus joining the fractured bones laterally.

EXPERIMENT 19.—Cat 19 was killed sixty-three days after the fracture. The same operation was performed as on Cat 16—circular division of the periosteum and bone with the Gigli saw. When the cat was killed, firm bony union with marked overriding was apparently present.

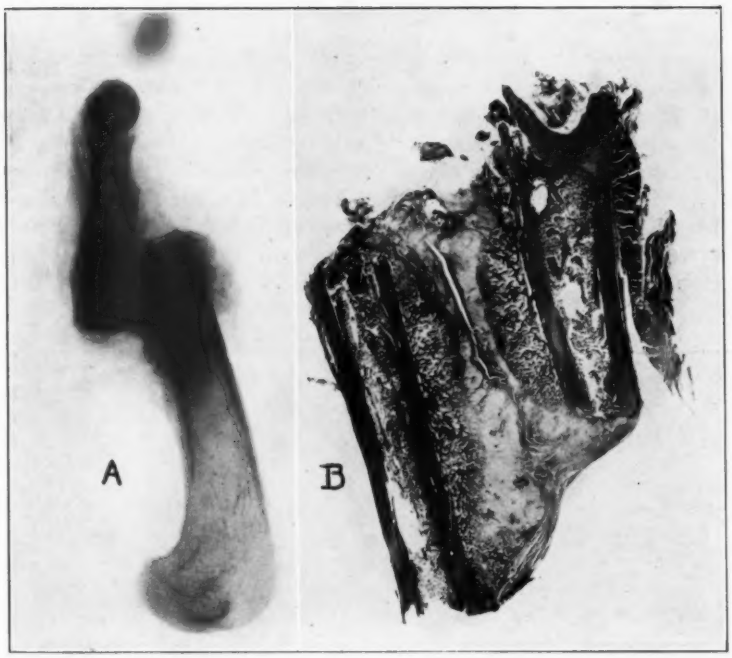

Fig. 19.—*A*, fractured humerus of Cat 18; *B*, stained slide cut from fractured humerus of Cat 18.

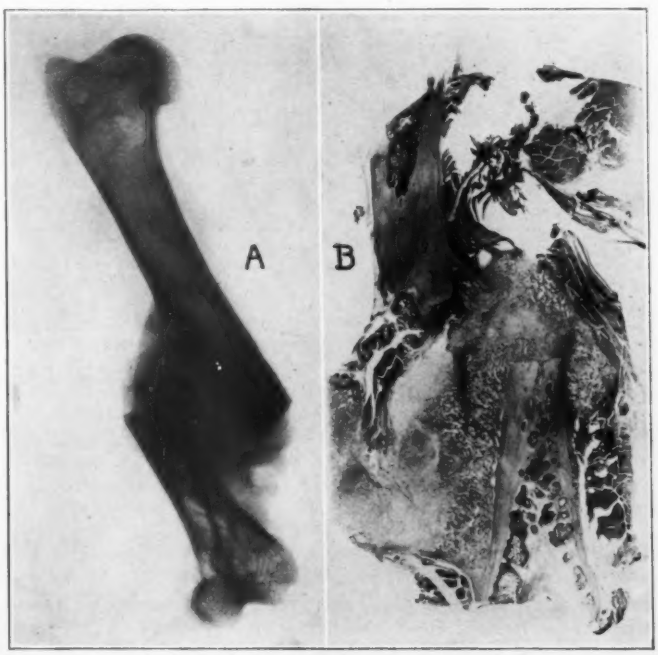

Fig. 20.—*A*, fractured humerus of Cat 19; *B*, stained slide cut from fractured humerus of Cat 19.

Examination of Stained Slide.—The ends of the bones had not overridden at all, but there was some lateral displacement at the seat of fracture. The ends of the bones had been caught obliquely by the microtome knife, so that it was impossible to say whether or not their marrow canals were still open. They were firmly united by a mass of new bone which had been formed from cartilage and was densely spongy in its texture. This new bone was continuous with that of the cortex in the neighborhood of the end of each fragment, as well as with the very end of each fragment itself.

Summary.—There was firm union of the fragments by bone developed from cartilage.

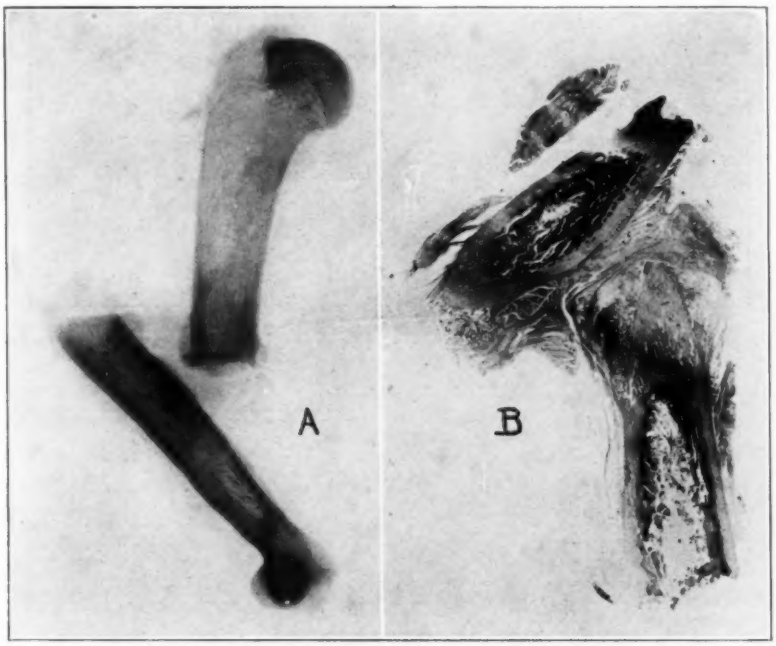

Fig. 21.—*A*, fractured humerus of Cat 20; *B*, stained slide cut from fractured humerus of Cat 20.

EXPERIMENT 20.—Cat 20 was killed thirty-six days after the fracture. The same operation was performed as on Cat 17, the saw breaking, and the division of the bone being completed with Liston bone forceps.

When the cat was killed, the wound was healed, and the hair had grown over the site of operation. The bones, with the tissues immediately surrounding them, were removed. They were apparently overlapped about 2 cm., and there was no sign at all of union.

Examination of Stained Slide.—The two fragments articulated at an angle, or rather the end of one fragment articulated with the side of the other fragment at almost a right angle, about 2 cm. from its extremity. The end of one fragment had been caught obliquely by the microtome knife so that the patency of its marrow canal could not be determined, but the marrow canal of the other was almost completely shut off with new bone trabeculae whose spaces were filled with dense fibrous tissue. Apparently these bone trabeculae were being

formed from fibrous tissue, for within the marrow canal there was no evidence of endochondral bone formation. On the outside of the end of each cortex of this fragment, the stained slide showed, beneath the periosteum, a fairly regular semicircle of new bone, forming from cartilage, as if in the blind effort to accomplish the classical wiped joint usually found in the healing of fractures. But all this new bone was well encapsulated by fibrous tissue, and showed no tendency to spread across to the other fragment, being separated from it by very dense fibrous tissue which contained clefts or rifts. This dense fibrous tissue extended over the entire end of the fragment, forming a thick cap for it, and passing down among the trabeculae in the central marrow canal as noted above.

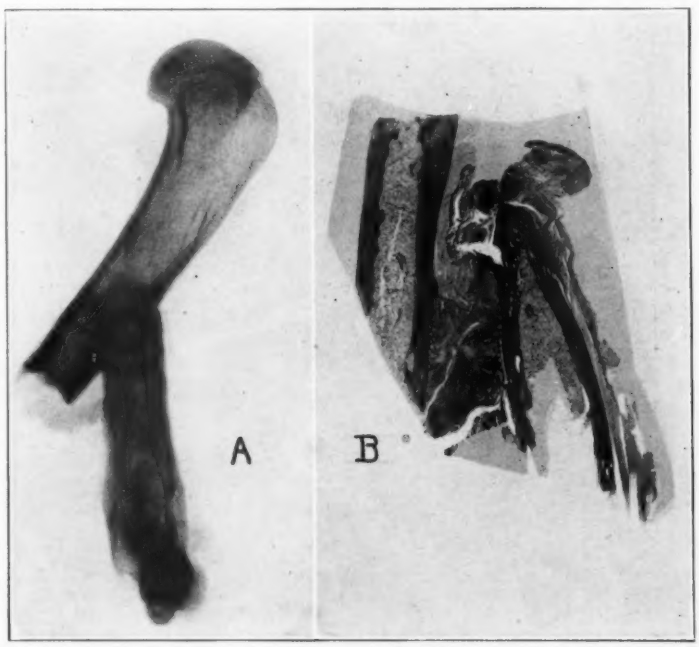

Fig. 22.—*A*, fractured humerus of Cat 21; *B*, stained slide cut from fractured humerus of Cat 21.

The other fragment was capped on the outside of its conical end by new endochondral bone, spongy in its interior but denser at its periphery. This cap of bone was covered almost completely by rather dense fibrous tissue.

Summary.—There was the formation of a new joint between the end of one fragment and the lateral aspect of the other. Internal and external callus was present.

THIRD SERIES

In this series a longitudinal incision was made in the periosteum, and the right humerus was divided by Liston bone forceps.

EXPERIMENT 21.—Cat 21 was killed forty-eight days after the fracture. A lateral incision was made on the fore leg; intermuscular dissection was carried down to the periosteum, and a longitudinal incision was made through the

periosteum. The periosteum was separated from the bone; the bone was divided with Liston forceps, and was sutured with deep and superficial catgut sutures, and a collodion dressing applied.

When the cat was killed the wound was well healed and the hair had grown over it. Marked overriding of the fragments was present, but no sign of union.

Examination of Stained Slide.—The marrow canal of one fragment was open, and in the marrow, close to the end, were irregular chips of bone or bone trabeculae, which for the most part appeared to be dead; but the nuclei of some stained well, so that one got the impression that they were partly chips of bone from the fracture being absorbed, and partly new bone building across the marrow canal. The ends of the cortex of this fragment were ragged,

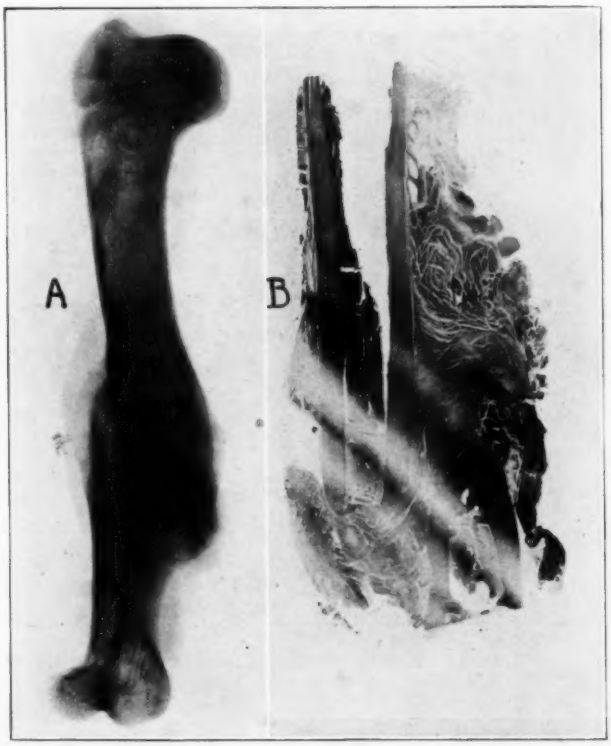

Fig. 23.—*A,* fractured humerus of Cat 22; *B,* stained slide cut from fractured humerus of Cat 22.

and the bone of the cortex on the far side from the other fragment stained poorly, while that of the cortex toward the other fragment stained much more distinctly. Across the end of this cortex and extending about half way across the end of the marrow canal was dense fibrous tissue, and this fibrous tissue ran across to the other fragment, showing in its structure a marked cartilaginous element as it neared the cortex of the latter. In this cartilage, formation of bone trabeculae was beginning, but, whether because of an artefact or not, these trabeculae were not apposed to the cortex. A small irregular slit lay between the intracartilaginous bone formation and the cortex.

The end of the other fragment had been caught at an angle by the microtome knife, so that the patency of the marrow canal could not be determined. Fibrous tissue extended from near the end of this fragment to the cortex of the other, and this tissue also showed much cartilage in the region of the latter cortex, with new bone trabeculae developing close to the cortical bone. These trabeculae were not separated from the cortex as were the others.

In the connecting tissue were irregular rifts or rents, one of them extending from a spot over the open marrow canal of the one fragment diagonally across, almost to the cortex of the other; and in this rent, as in some of the others, were organized masses of fibrin, with the typical shape of synovial villi. Indeed, the sides of the cleft might have been mistaken for synovial membrane.

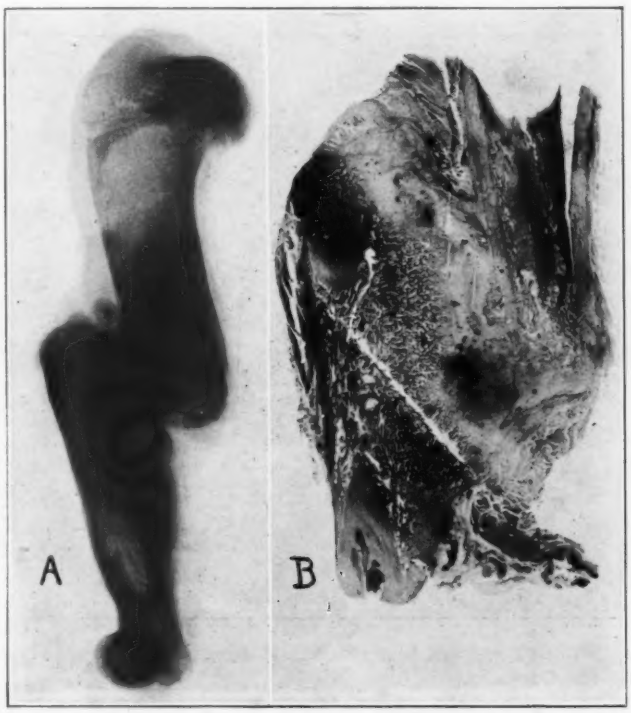

Fig. 24.—*A*, fractured humerus of Cat 23; *B*, stained slide cut from fractured humerus of Cat 23.

Summary.—In spite of the small intracartilaginous bone development, there was no indication in this specimen that bony union ever would take place. Everything pointed to the establishment of a new joint.

EXPERIMENT 22.—Cat 22 was killed sixty-two days after the fracture. The same operation was performed as on Cat 21. The animal was young. When it was killed there was no sign of infection. The wound had healed and the fur had grown over it. Apparently, there was firm union, with a large amount of callus.

Examination of Stained Slide.—The fragments overlapped and the end of one had been caught by the microtome knife obliquely, so that whether or not its marrow canal had been shut off by new bone could not be determined. On

the side of its extreme end, toward the other fragment, was a fairly large mass of newly developing intracartilaginous bone, and some distance from the end, also on this side, toward the other fragment and continuous with the cortical bone, was a narrow strip of new intracartilaginous bone still in the stage of development. Dense fibrous tissue in bundles separated this fragment from the other, and in this fibrous tissue were long and well defined rents. In places along the side of these rents, organizing fibrin could be seen with an appearance typical of synovial villi. Apparently, the formation of a new joint was rather well advanced.

The end of the marrow canal of the other fragment was well walled off with new bone, and the fibrous tissue dividing the two fragments passed over this new bone. Over the end of this fragment in the fibrous tissue, the rents

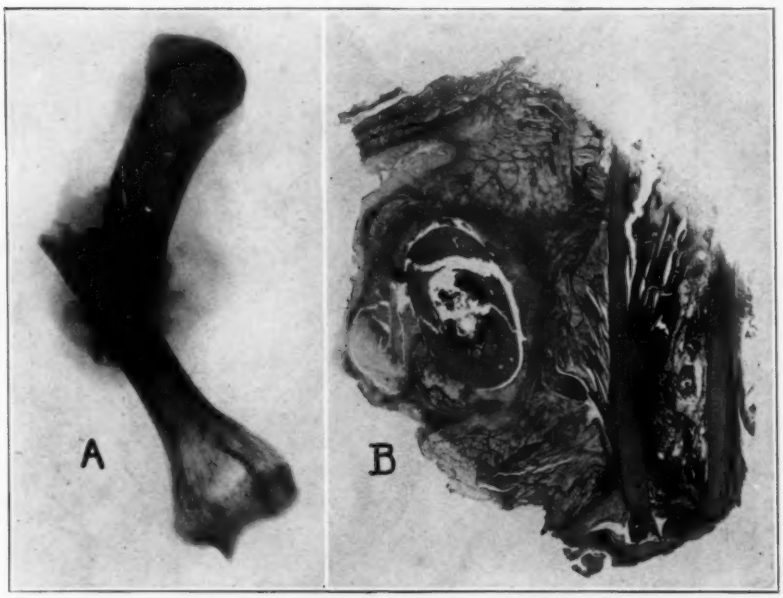

Fig. 25.—*A*, fractured humerus of Cat 24; *B*, stained slide cut from fractured humerus of Cat 24.

were continued with their villous formation. The sides of the cortex of this fragment showed no new bone, but in the fibrous tissue at the extreme end of this fragment, and separated from it by a small interval, was a small mass of new intracartilaginous bone.

Summary.—There was new joint formation. The bones were united by fibrous tissue containing clefts or rents.

EXPERIMENT 23.—Cat 23 was killed after forty-one days. It was evidently quite a young cat. The operation was the same as that performed on the two preceding cats. When the animal was killed, there was no sign of infection and the hair had grown over the wound. Apparently, firm union was present, with considerable callus.

Examination of Stained Slide.—The fragments overlapped about a centimeter, with an interval of about 0.5 cm. laterally. The marrow canals of both

bones were almost completely shut off by new bone trabeculae with a rather dense spongy structure. The two fragments were joined by a mass of cartilage and bone which was not homogeneous in structure. Near one fragment it consisted almost exclusively of cartilage and near the other fragment of bone. This mass of cartilage extended over the end of each fragment, and over almost the entire mass, the periosteum could be traced. New bone trabeculae, the so-called internal callus, were seen on the inner aspect of the cortex of one fragment, and in its central canal.

Summary.—There was cartilaginous callus, binding the two bones together laterally. Ossification of this cartilage was well advanced. The ossification was proceeding from the cortices, and apparently in time would be complete.

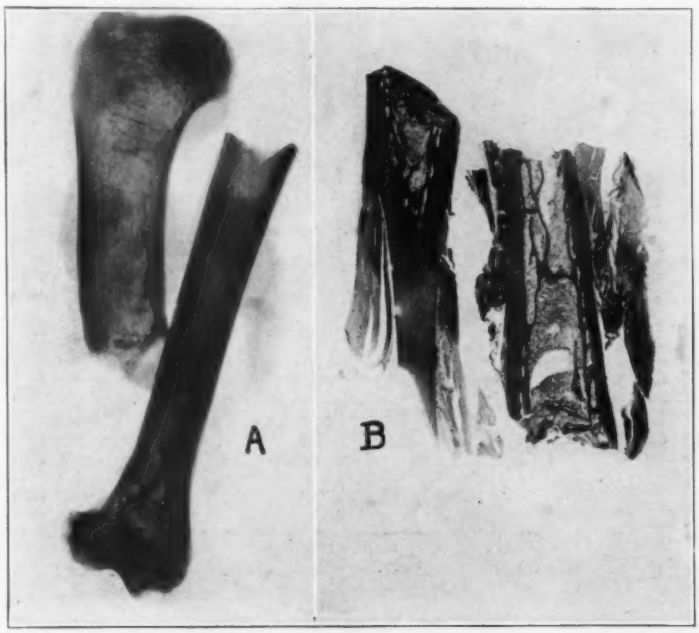

Fig. 26.—*A*, fractured humerus of Cat 25; *B*, stained slide cut from fractured humerus of Cat 25.

EXPERIMENT 24.—Cat 24 was killed after twenty-two days. The same operation was performed as on the three preceding cats. When the cat was killed, the wound in the skin was healed. The fragments had overridden and there was no evidence of union. On cutting down to the fracture a focus of pus was opened, in which the distal end of the proximal fragment lay bare and rough.

Examination of Stained Slide.—The fragments had been cut at such an angle by the knife that little could be told as to topography. Each fragment showed beginning endochondral bone formation on the outside of its cortex, but no attempt at union of the two fragments was evident. They were separated by an interval of about 0.5 cm., and this interval was occupied by muscle and fibrous tissue in rather loose bundles, with many rifts.

Summary.—While it was too early to say positively, apparently the bones would not have united in this case. Infection about the end of one fragment.

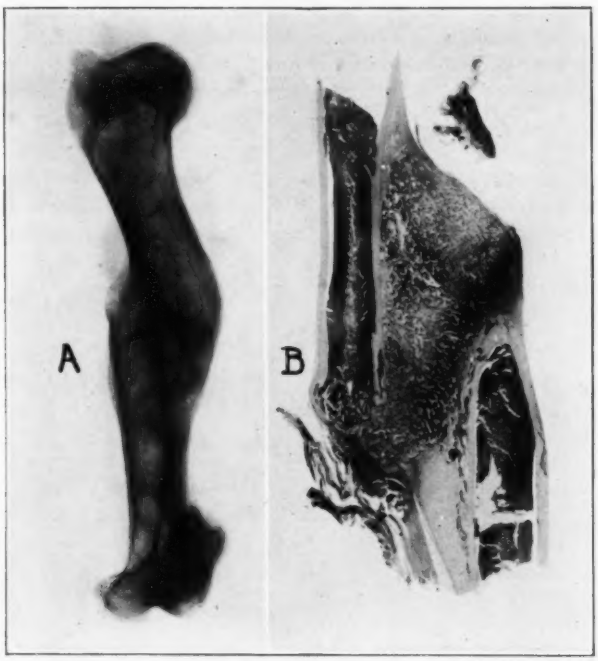

Fig. 27.—*A*, fractured humerus of Cat 26; *B*, stained slide cut from fractured humerus of Cat 26.

Fig. 28.—Cross section of tibia of cat, showing trabeculae forming in the marrow beneath the hole made in the cortex; × 4.

EXPERIMENT 25.—Cat 25 died after four days. The operation was the same as that performed on the last four cats. The periosteum was separated from the bone with difficulty. The cat died of an unknown disease. There was no sign of infection about the wound. Marked ecchymosis was present, and the fragments were loose.

Examination of Stained Slide.—The end of each marrow canal was shut off by a blood clot, and in one of these clots were a number of small spicules of bone, evidently broken off at the time of fracture. The periosteum was thickened, and in the neighborhood of the fractured end hemorrhage had taken place beneath it.

Summary.—There was hemorrhage in the marrow, and under the periosteum.

EXPERIMENT 26.—Cat 26 was killed after fifty-five days. The same operation was performed as on the preceding five cats. When the cat was killed the wound had healed, and the fur had grown over it. Moderate callus was present, with firm union.

Examination of Stained Slide.—The fragments had overridden somewhat less than a centimeter, and laterally were about 0.5 cm. apart. The end of one bone had been caught at an angle by the microtome knife, so that the cortex was pointed, and shut off the marrow canal in the slide. Whether or not the canal actually was shut off, it was impossible to tell. The marrow canal of the other fragment was partially shut off by new bone trabeculae. A few scattered trabeculae were also seen in the marrow in the immediate vicinity of this attempt at closing off. The overlapping fragments were tightly welded together by a mass of new bone, which evidently had been developed from cartilage, but there was no new bone on the off side of either fragment, and no evidence of any internal callus—no new bone trabeculae on the inside of the cortex. The new bone callus was continuous directly with the apposed cortices. The periosteum was continuous over much of the new bone, but on account of the stripping of the soft parts from the specimen on the slide, its continuity could not certainly be determined.

Summary.—There was firm bony union, apparently through the medium of cartilage. The new bone was directly continuous with that of the apposed cortices.

COMMENT

These three sets of experiments were undertaken to demonstrate the truth of a theory which I have taught my classes for a number of years, namely, that after a fracture, the periosteum serves as a bridge in which nature builds bone, and that nonunion is usually due to the absence of this bridge.[1] Not only do the experiments fail to demonstrate this, but they show that the theory was false. In none of the slides was there any evidence of any active part taken by the periosteum in the actual formation of new bone, and yet the most cursory inspection of the results demonstrates that the periosteum must play an important rôle of some kind, for where it was divided, there nonunion regularly resulted. The exact rôle of the periosteum in bone formation, and especially in the healing of fractures, has been the subject of much discussion. Indeed, the whole subject of the formation of

1. Ely, L. W.: The Formation of Bone, Ann. Surg. **69**:225 (March) 1919.

bone is still far from settled. These experiments throw light on both problems; but before considering them, we may profitably spend some time on a general study of bone formation. The study cannot be opened better than by an accurate definition of the terms employed.

Bone is an animal substance composed of organic material consisting of cells and intercellular substance, the latter impregnated with salts of lime and magnesium.

Marrow is the soft tissue within the bone—all the soft tissue within the bone, except the bone cells themselves. Its situation, not its composition, determines its name. Wherever there is bone there is marrow, and no matter what the composition of a tissue may be, if it is not situated within the bone, it is not marrow. Thus, small pockets of tissue with all the characteristics of marrow are occasionally seen in the region of the joints, on the outside of the cortex, immediately under the periosteum; but this is not marrow.

Periosteum is the tissue which covers bone in all situations not covered by the articular cartilage. As with the marrow, the situation of this tissue determines its name, not its structure. It usually consists of fibrous tissue, but in places it may consist of cartilage or of fibrocartilage.

If one looks through a microscope at the periosteum and the cortex of a growing bone, that is, of a bone of a child, one will see, lying on the cortex, numbers of bone cells or of osteoblasts. The trabeculae of the bone within the shaft present the same appearance whether they are being built up or torn down. These cells on the outside of the cortex, in a sense, may be said to be part of the periosteum, but really they have nothing whatever to do with it. They belong to the bone on which they lie. Nevertheless, they are responsible for the widely held opinion that the periosteum has two layers in its structure. Ollier first promulgated this theory, and poetically likened the periosteum to the bark of a tree, with its cambium layer. His theory gained almost universal acceptance until MacEwen challenged it a few years ago.

In the quiescent bone of the adult, nothing like a second layer of the periosteum can be made out. This subject is really not a question for debate. We cannot assume the presence of two layers because our clinical observation teaches us they should be there, and as far as I have been able to find out, no evidence other than clinical ever has been adduced for the presence of two layers of the periosteum in the adult bone.

Fibers of the periosteum run down into the bone cortex; but, as soon as they enter the bone, they cease to be part of the periosteum, and become part of the marrow.

Cartilage is a connective tissue consisting of cells and of a homogeneous or fibrillar basement substance impregnated with chondromucin.

Typical cartilage is easily identified; but in certain cases the identification is only possible by recognizing the peculiar cartilage cells in their capsules. When these appear in fibrous tissue, we call the tissue fibrocartilage.

THE FORMATION OF BONE

Two theories have been held as to the formation of bone in general. According to the first, the metablastic, the members of the connective tissue group have the inherent power to change from one to another under certain circumstances, without the influence of any active outside agent. This theory has been almost abandoned, and has been replaced by the osteoblastic theory. According to this theory, bone is formed as the result of the action of a bone forming cell, the osteoblast. We assume that there is such a cell, but we do not know its derivation, and we have no means of identifying it under the microscope. It is supposed to be a small cell, with a deeply staining, round or polyhedral nucleus, frequently seen on the borders of bone trabeculae. When we see such cells on the trabeculae, we are wont to say that they are osteoblasts, and that bone is being built up in this situation. This, however, is not always the case. Similar cells are seen in that situation when we know very well that the bone is being torn down. Moschcowitz [2] says that the osteoblast is simply a differentiated endothelial cell from the wall of the blood vessel. At any rate, unless the osteoblast is the same thing as a cartilage cell, it must be brought to the tissue to be converted into bone, either in the blood stream or in the wall of the blood vessel, for bone formation never begins in cartilage, or, for that matter, in any other tissue, until the blood vessel pushes its way in.

We assume, then, some specific cell, the osteoblast, as the active agent in the formation of bone—the builder, so to speak. The next question is: Out of what is bone built? It may evidently be built out of one of a number of materials. It may be built out of cartilage—intracartilaginous formation. It may be built out of fibrous tissue—intramembranous bone formation. Apparently, bone may also be manufactured out of amorphous or granular necrotic material, as in old inflammatory processes in lymph nodes, or in kidneys whose arteries have been tied off.[3]

The third thing that is necessary for bone formation is a stimulus, pathologic or physiologic, as the case may be. Function is a stimulus, as is the mere presence of bone. If a piece of bone is removed from a live animal, and then if it is immediately buried in the same animal,

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2. Moschcowitz, Eli: The Relation of Osteogenesis to Ossification, Bull. Johns Hopkins Hosp. **27**:71 (March) 1916.

3. Liek: Zur Frage der heteroplastischen Knochenbildung, Arch. f. klin. Chir. **80**:279, 1906.

the bone and its contained marrow die.[4] Whatever happens thereafter in that piece of bone and marrow, therefore, must be the result of activity from the surrounding tissues. The first thing that happens is the pushing in of blood vessels from these tissues, and, if the fragment is covered in any part of periosteum, at that part vascularization first takes place.

Following the penetration of the blood vessels, two distinct and opposite processes start in this sterile, dead piece of bone; on the one hand, rebuilding with new, live bone, and on the other hand, clearing away and absorption of the fragment. According to circumstances, one or the other of these processes will prevail, and the fragment will persist and even, in certain circumstances, increase in size, or it will disappear. The mere presence of the dead bone causes new bone to be formed (one stimulus), but if there is no function (a second stimulus) absorption will exceed rebuilding, and the fragment eventually will disappear.

A third stimulus is irritation, as for instance, about an old suppurative osteomyelitis. Normal growth carries with it a fourth stimulus, whose existence we recognize, but whose nature we do not understand. We note that, at a certain period of existence, the blood vessel penetrates the cylinder of cartilage or the epiphysis, and initiates ossification, and that until full growth is attained, nature continues to lay down new bone on the outside of the cortex, and then ceases. Just what starts this physiologic bone growth, and just why it stops, we do not know. We observe it, and let it go at that. But wherever bone is being formed, the blood vessel is the active agent in the process.

We see then that bone may be formed either in the marrow or, perhaps, in the periosteum at the surface; but neither of these two tissues actually forms bone, and bone may be formed without either of them, as in cartilage.

It is well known that the ends of the cortex of a fractured bone possess in themselves little or no power of repair. If a hole is bored in the cortex of a long bone of a laboratory animal, the fractured end of the cortex takes very little part in the subsequent healing. Nature does not simply bridge across the hole in the cortex with new bone, as one would think, but she carries out her purpose by means of an internal and an external callus.

The external callus is small in amount, and consists of scattered trabeculae, mostly in the immediate neighborhood of the cortex beneath the periosteum. Where the hole was made in the periosteum, that is,

4. Ely, L. W., and Cowan, J. F.: A Study of Buried Bone, J. Orthop. Surg. **1**:100 (Feb.) 1919; An Experimental Study of Buried Bone, Ann. Surg. **70**: 747 (Dec.) 1919.

immediately over the hole in the bone, there the formation of bone occurs quite late. The major part of the healing is brought about by the so-called internal callus, that is, by bone trabeculae laid down in fibrous tissue in the marrow, and connecting with the inner aspect of the cortex. This makes a bridge of spongy bone in the marrow across the hole, whose trabeculae connect through the hole, by trabeculae laid down in fibrous tissue and perhaps in cartilage, with the trabeculae in the external callus. The resulting mass of callus of spongy bone has been likened in shape, by E. H. Nichols, to a collar button, with its large flange in the marrow, and its small flange in the periosteum. The connecting shank slowly increases in density until it fills up the hole, but does not establish continuity with the cortical bone at its side until a very late period. In other words, the cortical bone about the hole has played a passive part in the whole process. Everything has been done from the internal and external aspect of the cortex, in the marrow and beneath the periosteum.

We have no means of ascertaining how nearly the foregoing process is imitated in an accurately adjusted fracture of a long bone. The shank of the collar button is probably infinitesimal in thickness, and the roentgen rays indicate that the large flange is not in the marrow but in the periosteum. In fact, the whole essential part of the union seems to take place in, or under, the periosteum, and this roentgenographic phenomenon has gone far to strengthen the theory of the "bone forming" function of the periosteum.

That the periosteum plays an important rôle in the healing of fractures is evidenced by other facts, notably by the fact that nonunion is notoriously frequent in those bones or portions of bone not covered by periosteum: e. g., the neck of the femur, the head of the radius, and perhaps the carpal navicular in the region where it is usually fractured. On the other hand, we know that even in these fractures, if we can hold the fractured surfaces firmly together in complete immobility, union may be expected. This union could take place in only two ways, namely, by direct union between the fractured surfaces or by the formation of an internal callus. Apparently, an external callus does not form in the absence of the periosteum. In other words, in the absence of the periosteum, firm apposition and absolute immobility are necessary for union; in the presence of periosteum, they are not.

Nature has the greatest difficulty in bridging the smallest space with bone, and clinically it appears that some function of the periosteum is concerned in throwing the first bridge across. Just what this function is, has been the subject of much dispute.

There is a widely accepted theory that two raw bony surfaces brought together will unite. As has been said, they will not unite

unless held firmly together in immobility. This is true not only of fractures but also of resections. After resections also, two processes are set in motion, one of joint building, and the other of ankylosis. In the human subject, the knee is about the only large joint in which bony ankylosis regularly can be obtained. In the others, fibrous ankylosis usually follows a resection. In the knee, two extensive bony surfaces can be brought into close apposition, and can be held firmly together. In other joints, these indications cannot be fulfilled. The elements of extensive apposition and immobility must be the determining factors in the human knee, for after resection of the dog's knee, bony ankylosis is very hard to secure. A new joint usually results.[5]

The first thing that attracts our attention in a consideration of the results of the experiments is the difference in the proportion of bony union to false joint in three series. In the first series, that with simple fracture, bony union regularly resulted if the cat was permitted to live for five weeks. In the second series, in which the periosteum was divided circularly, nonunion was the rule. Bony union took place in only one cat of this series. In the third series, that in which the periosteum was slit, bony union was about as frequent as new joint formation. From these facts the first conclusion to be drawn is:

1. *The periosteum has a function to perform in the healing of fractures.* The periosteum is not indispensable, for union may take place when it is slit or divided.

The next thing that interests us is the exact method of union. The specimens throw much light on this. In the first place, we note an entire absence of any bone-forming action in the periosteum. It is not even serving as a bridge or scaffold for the formation of bone, a function which I have persistently assigned to it. Its whole function seems to be to protect, to contain the soft callus between the fragments, to hold it against the fragments, so to speak. The specimens show that MacEwen was essentially right in regarding the periosteum as a limiting membrane. I have hitherto denied this. I was wrong.

As to the so-called internal callus, my specimens show no evidence of any effective rôle played by it in the process of union. Sometimes scattered trabeculae appeared within the marrow canal, and sometimes there was no bone formation there at all; but even when present, the trabeculae were apparently not serving any useful purpose. It seems, then, that while this internal callus is the chief means whereby nature repairs the damage done by boring a hole in the cortex, when there is

5. Ely, L. W.: Experimental Resection of the Dog's Knee Joint, Ann. Surg. **70**:586 (Nov.) 1919. Ely, L. W., and Cowan, J. F.: Experimental Resection of the Dog's Knee Joint. Bone and Joint Studies, I, Stanford University, Published by Stanford University, 1916.

an actual solution of continuity between the fragments of a fracture, the internal callus is a negligible factor. This is in line with the impression which one gets from studying roentgenograms of fractures clinically. These show that the whole process of repair takes place outside the cortex.

In almost all our specimens, marked displacement of the fragments had taken place, and they were separated by a distinct interval. This interval, bounded on two sides by cortex, and on two sides by periosteum, became filled with cartilage, fibrous tissue and fibrocartilage. Union of the two fragments took place by ossification of this mass of cartilage and fibrocartilage very much as ossification takes place in an epiphysis, by the penetration of blood vessels. The ossification advances from the cortex, and is especially marked in the angle made where the periosteum leaves the cortex. In no case was there any evidence of bone formation along the periosteum where it stretched across between the fragments. In other words:

2. *Ossification of the soft callus takes place from the external aspect of the cortex.* This also agrees with roentgen-ray evidence. What has been assumed from roentgen-ray evidence, however, to be a bony bridge built by the activity of the periosteum, is really the result of bone formation proceeding from the cortex. The few experiments which were allowed to run for a considerable time indicated that after bony union was complete, the apposed and overlapping cortices were being torn down, and that a rearrangement of the bone architecture was going forward. Presumably, a new cortex would be formed in the bony callus, and a central medullary canal would be established within it.

In the cases of nonunion, the fundamentals of the formation of the soft callus were the same as in the other cases, except that the production of fibrous tissue was possibly more abundant. New bone developing from cartilage appeared on the outside of the cortex in these cases also. The chief distinguishing mark in these two series was the formation of rifts in the fibrous tissue of the soft callus, and when the soft callus was transformed partially or completely into cartilage and bone, the large rift or series of rifts constituted a regular joint, lined by cartilage or by fibrocartilage, sometimes in places showing a distinct villous formation, like that of a synovial membrane.

This formation of a new joint is the rule in the series of experiments in which circular division of the periosteum was carried out. Only one case of the series showed bony union. The series in which the periosteum was slit does not show this almost uniform tendency. The cases are too few for accurate judgment, but, roughly, bony union is about as frequent in the uninfected cases which have run a sufficient time as is new joint formation. In other words:

1. When the periosteum is intact, bony union is to be expected.

2. When the periosteum is completely divided, bony union is not to be expected.

3. When the periosteum is slit, bony union may or may not take place.

CONCLUSION

After an ordinary fracture, hemorrhage takes place from the marrow canal under the periosteum. The periosteum is stripped up from the cortex by this hemorrhage and by the fracture itself. Then come the deposition of fibrin, the formation of granulation tissue and the formation of cartilage and fibrocartilage in the space beneath the stripped-up periosteum. Probably the function of the periosteum is only important in the early stages, up to the formation of the cartilaginous callus. The periosteum probably serves to keep the hemorrhage from escaping and the granulation tissue undisturbed. It has no bone-forming function, and bone is not built out of it. The subsequent ossification of the cartilaginous callus is carried out almost entirely, if not exclusively, from the external aspect of the cortex. The internal callus plays no effective part in the union. It is rudimentary when it is present.

FRACTURE OF THE TIBIAL SPINE

AN EXPERIMENTAL STUDY *

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SAN FRANCISCO

The present article is the result of experimental observations on fracture of the tibial spine. The work was done on cadavers. It consisted mainly of demonstrations before classes of students, during the regular courses on fractures and dislocations, and of experiments made at other times. Textbooks are particularly silent on fractures of the tibial spine when they are not a complication of a more serious injury to the knee.

This form of fracture occurs most frequently as a complication of dislocation of the knee or of fracture of the tibial tuberosities. As a simple uncomplicated fracture it is apparently not so rare as one might be led to believe from textbooks and treatises on fractures in general. In such injuries to the knee as the so-called sprains or twists, it passed unrecognized before the introduction of the roentgen rays.

It is not my object at present to consider fracture of the tibial spine as a complication, but to consider it as an uncomplicated fracture with a minimum amount of damage to some of the ligaments of the knee joint.

ANATOMY

It is essential to consider briefly the salient anatomic characteristics of the ligaments of the knee joint in order to follow closely what will be said regarding the experiments and mechanisms involved and also to be able clearly to account for the pathologic condition.

The knee joint is the largest and one of the most superficial joints of the body. It owes its remarkable strength not only to its bony construction but also to the strong resisting ligaments, reenforced by one of the strongest fascias of the body—the fascia lata, together with the tendon of the powerful quadriceps extensor muscle, which binds and holds the parts together. The expansion and mutual blending of these fibrous structures, along with the other ligaments to be mentioned, add stability to the osseous constitution of the articulation, and enable it to withstand the leverage of the two longest bones of the body. The great size of the bone ends is important in determining more advantageous leverage by which the strain on the ligaments is lessened.

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It may be well to remember that the knee joint in some of the lower animals is composed of two separate joints, one for each condyle, and the crucial ligaments of man are the representatives of lateral ligaments when these joints exist as separate entities.

Crucial Ligaments. (Fig. 1).—These ligaments of the knee are interosseous, being situated within the joint but external to the synovial membrane. They are named anterior (lateral) and posterior (medial) from the position of their attachment to the tibia. Gray says that they possess considerable strength, while Treves[1] refers to them as being very powerful.

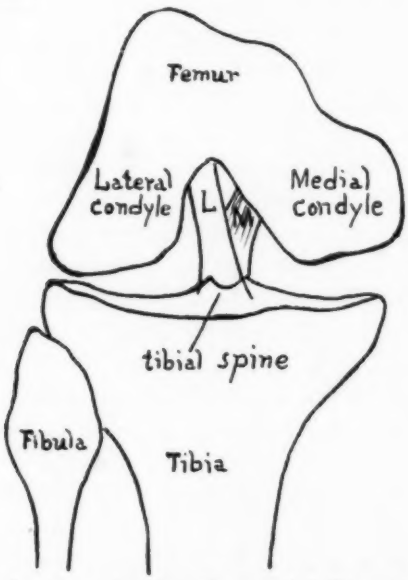

Fig. 1.—Outline drawing showing the crucial ligament of the knee joint: *L*, anterior crucial ligament; *M*, posterior crucial ligament.

The anterior crucial ligament is attached to the depression in front of the spine of the tibia, being blended with the anterior extremity of the lateral meniscus; and passing obliquely upward, backward and outward, it is inserted into the inner and back part of the lateral condyle of the femur.

The posterior crucial ligament is stronger, shorter and less oblique in its direction than the lateral. It is attached to the back of the depression behind the spine of the tibia, to the popliteal notch and to the posterior extremity of the lateral meniscus, passing upward, forward and inward, to be inserted into the outer and forepart of the inner condyle of the femur, where it blends with the ligamentum posticum.

1. Treves, Frederick: Surgical Applied Anatomy, Ed. 7, revised by Arthur Keith and W. Colin Mackenzie, 1917.

Collateral Ligaments.—There are two of these, the lateral and medial. Treves considers them comparatively feeble. The lateral ligament consists of two parts, the fibular collateral and a short, or posterior, portion.

The fibular collateral is a strong, rounded fibrous cord, attached above to the back of the lateral tuberosity of the femur; below, to the lateral part of the head of the fibula. Externally, it is covered by the tendon of the biceps muscles, which divides at its insertion into two parts, separated by the ligament. The tendon of the popliteus muscle and inferior external articular vessels and nerves passes beneath it. Piersol considers this ligament as truly distinct.

The short, or posterior, part may be absent. It is an accessory bundle behind and parallel to the preceding. It is attached above to

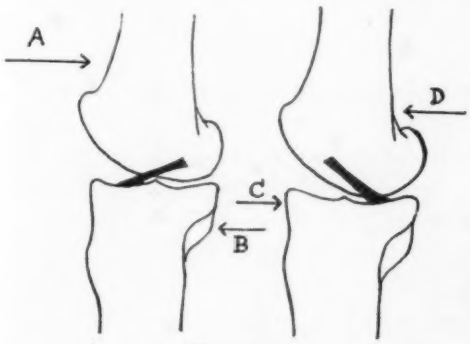

Figure 2

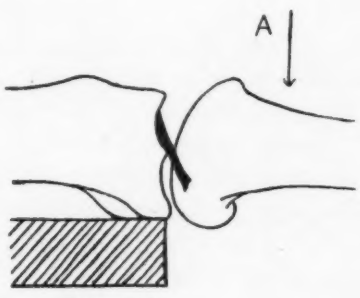

Figure 3

Fig. 2.—Outline drawing showing where force was applied to throw tensile stress upon the anterior crucial ligament (left); and upon the posterior crucial ligament (right).

Fig. 3.—Outline drawing showing how the leg was supported and where force was applied to produce fracture of the tibial spine as shown in Figure 4.

the lower and back part of the lateral tuberosity of the femur; below, to the styloid process of the fibula and is inseparable from the capsule. Passing beneath it are the tendon of the popliteus muscle and the inferior lateral articular vessels and nerves.

The medial, or tibial collateral, ligament is a well defined, strong, flat fibrous band, thicker behind than in front. It is attached above to the medial condyle of the femur; below, to the medial tuberosity and medial surface of the shaft of the tibia to the extent of about 2 inches (5 cm.). It is crossed, at its lower part, by the tendons of the sartorius, gracilis and semimembranosus muscles, a synovial bursa being interposed. Its deep surface covers the anterior portion of the tendon of the semimembranosus with which it is connected by a few fibers, the synovial membrane of the joint and the inferior articular

vessels and nerve. It is adherent to the medial meniscus. Piersol considers this ligament as only a part of the capsule artificially separated. Both collateral ligaments are situated nearer the back than the front of the joint.

Ligamentum Patellae.—This ligament is that part of the quadriceps extensor tendon in which the patella is a sesamoid bone. It is a strong flattened fibrous band, about 2 inches (5 cm.) long, and inserted into the tibial tubercle. It is fused at the sides with fibrous expansions from the quadriceps extensor muscle.

Capsula Articularis.—This forms the ligamentum posticum which is strengthened above by oblique fibers from the tendon of the semimembranosus muscle, forming Winslow's ligament. The capsule as a whole is very thin but strong fibrous membrane filling in the intervals between the stronger parts named above, which in part are inseparable from it.

SURGICAL ANATOMY

Almost all of the facts presented here have been reviewed on the anatomic preparations in the teaching collection of the laboratory of surgical pathology of the Medical Department of Stanford University. It is very important that they be repeated although more or less extant in textbooks and in the literature.

Regarding the crucial ligaments, Treves states that they are more or less tense in all extreme positions of the joint. The anterior ligament especially resists extension, forward displacement of the tibia and rotation inward of the leg; while the posterior resists extreme flexion and displacement backward of the tibia. In the moment of extension, the tibia slides slightly forward and is rotated slightly outward. In flexion it glides backward and rolls slightly inward. The center of rotation of the tibia, when near the position of extreme extension, passes behind the lines joining the points of insertion of the collateral ligaments, so that the knee automatically locks in the position of extreme extension. In this position the locking arrangement permits stability with a minimum of muscular action in standing. Therefore, the standing position is less fatiguing than it otherwise would be.

On the whole, extension generally is limited by the crucial ligaments; flexion by the ligamentum patellae and anterior part of the capsule, in addition to the crucial ligaments.

We should be familiar with the fact that rotation of the knee is possible only in the flexed position. The patellar ligament is tense in flexion, and relaxed in extension when the quadriceps extensor muscle is relaxed. Acting in conjunction with the anterior portion of the capsule, it limits excessive flexion, especially in the emaciated, less so in the adipose, as the soft parts are more prominent and naturally

diminish the range of flexion. Both collateral ligaments are tense during extension and relaxed during flexion. Together they withstand the lateral strains and also check hyperextension and outward rotation. The ligamentum posticum limits extension.

Lange believes that the crucial ligaments together limit or prevent forward and backward sliding, and that both are more or less tense in all positions of the knee joint, with the exception of flexion. Here he disagrees with Treves. Davis states that these ligaments are not tense in all positions, for in flexion they become slightly relaxed. Robert Jones [2] states that both crucials check inward rotation of the tibia.

It must be borne in mind that no two joints are exactly alike as regards the relative length, strength or size of the parts. This natural variation no doubt accounts for slight differences of opinion among authors.

EXPERIMENTS

Having considered the normal functions of the ligaments of the knee joint, it is logical to inquire what happens when excessive stress is thrown upon the joint in various directions. The following questions set forth the problems involved:

1. What occurs when force is applied to the lower and anterior part of the thigh just above the condyles of the femur, in a backward and slightly outward direction, with the leg in extension and fixed?

2. What occurs when force is applied to the upper and back part of the leg, when it is extended and the thigh is fixed?

3. Can fracture of the tibial spine, rupture of a crucial ligament, or avulsion of a fragment of bone from the femoral condyles be produced without visible or, at most, but slight injury to the collateral ligaments, rupture of fascia, fracture of the femoral condyles or tibial tuberosities other than those produced by direct pull on the crucial ligaments?

4. What happens when forcible stress is exerted laterally against the knee when in a state of extension? When in a state of flexion? Which gives way first, the collateral or the crucial ligaments?

5. What happens when forcible stress is exerted in a rotatory direction, either when the leg is in extension or flexion, outward rotation being normally limited by the collateral ligaments, and inward rotation normally limited by the anterior crucial ligament?

In the living subject as well as in the cadaver, stress will unavoidably be exerted in several directions simultaneously, the results being influenced by position and the individual anatomic peculiarities in each case.

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2. Jones, Robert: Sect. VIII, Injuries to Joints, Oxford Loose-Leaf Surgery, New York, Oxford University Press **1**:812, 1918.

Technic.—The part to which the force is to be applied is covered by a thick pad, formed usually from an ordinary sheet which is folded a number of times until it is about 12 inches (30 cm.) square. The blow is struck with a club made from a scantling 4 inches (10 cm.) wide, thus giving a broad surface. The joint after production of the injury is opened by making a large oval patellar flap which is reflected downward, giving a good exposure of the interior of the knee.

REPORT OF EXPERIMENTS

Experiment 1.—This was performed on the cadaver of a young, husky colored man, whose limbs were rigid. The body was placed in a prone position. The distal extremity of the right thigh (femur) was supported on a 4-inch (10 cm.) block placed beneath the femoral condyles. The distal part of the leg was supported in a similar way. The thick pad was thrown over the upper part of the sural region, and a heavy blow was delivered in such a way as to drive the tibia forward and a little inward on the femur (Fig. 2 *B*), the object being to produce tensile stress in the direction of the longitudinal axis of the anterior crucial ligament.

Result.—This was doubtful on account of the great muscular rigidity. The knee joint was opened as described above. An examination of the interior of the joint demonstrated the parts intact. The blow was repeated with the joint open.

Examination.—Fracture of the tibial spine occurred close to the insertion of the anterior crucial ligament.

EXPERIMENT 2.—The same technic and mechanism were employed on the left knee.

Result.—Rupture of the anterior crucial ligament occurred.

EXPERIMENT 3.—This was performed on the cadaver of a middle aged white man, whose extremities were rigid, with possible flexion of not more than 10 degrees. The body was placed in a supine position. The tibia of the left knee was supported on a block, the end of which was flush with the articular surface of the tibia (Fig. 3). A pad was applied over the distal and anterior surface of the thigh and a heavy blow was delivered just above the condyles (Fig. 3 *A*) in such a way as to drive the femur backward and a little outward, the object being to produce tensile stress on the anterior crucial ligament, in the direction of its longitudinal axis.

Result.—Laceration of the anterior crucial ligament occurred.

EXPERIMENT 4.—The same technic and mechanism were employed on the right knee as in Experiment 3.

Result.—Laceration of the anterior crucial ligament resulted.

EXPERIMENT 5.—This was performed on the cadaver of a white man, aged 91 years, a laborer. The body was placed in a supine position. The left knee was rigid, very slight flexion being possible. The proximal extremity of the leg (tibia) was supported as in Experiment 3. A pad was thrown over the distal extremity of the thigh and a heavy blow was delivered just above the condyles of the femur, the object being to produce tensile stress on the anterior crucial ligament, as in Experiment 3.

Result.—A comminuted fracture of the distal third of the femur occurred, with an intercondylar line of fracture entering the joint, also fracture of the tibial spine—a small fragment of bone being torn off by avulsion through pull on the anterior crucial ligament.

EXPERIMENT 6.—The same technic and mechanism as in Experiment 5 were employed on the rigid right knee.

Result.—Fracture of the femur occurred at the lower third, as well as fracture of the tibial spine, consisting of a large fragment, measuring 1 by 1.5 cm.

EXPERIMENT 7.—This was performed on the cadaver of a white man, aged 82 years, whose knees were flexible. The body was placed in a prone position. The distal extremity of the left thigh (femur) was supported on a block which was placed just above the condyles. The distal extremity of the leg was supported by a block; the upper part of the sural region was covered by the usual pad and a heavy blow was delivered just below the tibial tuberosities (Fig. 2 *B*), driving the tibia forward and a little inward on the femur. The object was to produce tensile stress in the direction of the longitudinal axis of the anterior crucial ligament.

Result.—The plica synovialis patellaris was torn over the anterior crucial ligament; a small thin scale of compact bone was torn from the lateral and anterior surfaces of the medial condyle at the point of attachment of the posterior crucial ligament, the anterior ligament being stretched, rupturing some fibers (sprain).

EXPERIMENT 8.—The same technic and mechanism were employed on the right knee as in Experiment 7.

Result.—Fracture of the tibial spine occurred posteriorly, the fragment being about 4 mm. in diameter.

Comment.—Four cadavers were used for the eight experiments, with the following results:

(*a*) Fracture of the tibial spine occurred four times.

(*b*) Laceration of the crucial ligaments occurred three times.

(*c*) A fragment of bone was torn by avulsion from the femoral condyle once.

The fracturing of the femoral shaft in Experiments 5 and 6 was something unusual in the course of such demonstrations. The age of the subject has to be taken into account, for probably senile atrophy of the bone was present. In none of the other experiments was there macroscopic evidence of gross injury.

No experiments are given in which the femur was driven forward and slightly inward (Fig. 2 *D*), or the leg driven backward and slightly outward (Fig. 2 *C*), so as to produce tensile stress on the posterior crucial ligament in the direction of its longitudinal axis. The results of such experiments have been just as positive as those reported above, in which stress was thrown on the anterior crucial ligament. As in the case of the latter, one of three things occurs, namely: fracture of the tibial spine posteriorly, rupture of the ligament itself, or avulsion of a fragment of compact bone at the point of insertion of the ligament into the anterior and lateral surface of the medial condyle. Macroscopic or objective evidence of injury is just as unusual as in the experiments in which stress was thrown upon the anterior crucial ligament.

The results in Experiments 7 and 8 are not in accord with the usual results when stress is exerted upon the anterior crucial ligament. Here an element of variation appears. The anterior ligament was longer than usual or stretched, throwing the tension upon the posterior ligament. Dr. Oscar Allis once remarked to me regarding the constancy of results, "If we do not get the results we desire, we get something just as interesting and instructive".

Likewise, there is no report of results of experiments in which force was exerted laterally over the distal extremity of the femur or proximal part of the tibia. In such experiments the collateral as well as the crucial ligaments are involved. The results are: fracture of the femoral condyles, or in lieu of this the tibial tuberosity or, laterally, the fibular head; rupture of the ligaments, rarely; fracture of the tibial spine or rupture of the crucial ligaments, or avulsion of a fragment of bone from the femoral condyles through tensile stress upon these ligaments, with a varying degree of dislocation, depending on the direction and amount of violence. The giving way of the collateral or crucial ligaments is considered by Ross as an essential of dislocation.

The results of experiments in which rotatory and forcible stress was exerted through the leg, with the thigh fixed, or vice versa, are not so satisfactory on account of the rigidity which is usually present. It is believed that muscular action plays an important rôle in life. Fracture and rupture of ligaments are obtained, but of such a varying kind as to preclude positive predictions.

Dr. Ross [3] in his Experiment 48, by fixing the left femur and jerking the leg upward, produced a subluxation of the leg posteriorly on the femur. This leg was dissected with the following results: "Posterior subluxation was demonstrated, with sprain fracture of the inner and outer condyle through the agency of the posterior and anterior crucial ligaments, respectively, sprain fracture of the inner condyle through the agency of the tibial collateral ligament, sprain fracture of the posterior tibia between the tubercles through the agency of the posterior capsule, proved by microscopical section, separation of the fibers of the semimembranosus at the seat of its expansion into the posterior capsule and separation of some of the fibers of the inner head of the gastrocnemius. The two last named fiber separations were clearly visible to the unaided eye." This citation is enough to show the character and degree of injury in such cases.

In the cadaver, muscular influence as a vital factor is necessarily nil. Here the muscles act as splints and more or less neutralize the applied force, depending, of course, on the degree of rigor mortis, or

3. Ross, G. G.: A Study of Sprain-Fractures as an Essential to the Occurrence of Dislocation, Ann. Surg. **56**:599, 1912.

in the embalmed cadaver on the rigidity due to the embalming fluids, as in my Experiment 1 in which it was necessary to repeat the application of force.

CITATION OF PUBLISHED CASES

It will be elucidating and convincing to note carefully the similarity in some ways between my experimental cases and certain points in those that follow.

Dr. Sidney Lange [4] cites two cases of avulsion of the tibial spine:

> CASE 3.—Mr. McD., while wrestling, accidentally twisted his left knee and fell to the floor. He suffered great pain but was able to walk to the hospital. Examination was negative; but a roentgenogram revealed a tearing off of the tibial spine.
>
> CASE 4.—Mr. J. D., while attempting to alight from a moving street car, twisted his left knee and was thrown violently to the ground. He was unable to arise, owing to great pain in his knee. Examination was negative. A roentgenogram showed a tearing off of the medial condyle of the femur and an avulsion of the tibial spine.

These cases show sudden and severe strain on the knee joint, which gave negative evidence of bruising or any signs of fracture.

Callender [5] has reported the case of a boy (Case 17), aged 12, of healthy appearance, who gave a history of having "some days previously fallen upon some ice, and had struck his right knee a severe blow over the internal condyle, twisting his leg in his fall. He limped home but his complaints were made light of by his parents. Trouble followed. The knee joint was opened; the wound was allowed to close, pain followed, health failed, pus formed in the joint and the leg was amputated."

Results of examination of the museum specimen were reported thus:

> "Joint gave the ordinary appearance of an inflamed condition. The lower extremity of the femur, from the lateral condyle of which a slice has been removed, shows on the portion separated, close to the front of attachment of the anterior crucial ligament, a deep cavity lined by a smooth membrane. By its side is suspended a small, oval-shaped portion of bone, which, with its surface bare and rough, was loosely contained in it." The following comment is made: "There can be no doubt that this portion of bone had been unfastened from the condyle by some strain on the anterior crucial ligament and had necrosed, probably from neglect to which the boy was at first subjected."

The following very interesting and convincing case has been reported by Dr Ross: [6]

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4. Lange, Sidney: Ann. Surg. **48**:117, 1908.

5. Callender, G. W.: Fracture Into Joints, Rep. St. Bartholomew's Hospital **6**:51, 1870.

6. Ross, G. G.: A Case of Fracture of Intercondylar Spine of Tibia, Naval Med. Bull. **13**:294, 1919.

E. W. H., aged 30, ensign, U. S. S. *Douglass*, was admitted March 25, complaining of a swollen and painful left knee. He gave a history of having been struck on the posterior surface of the left leg, just below the knee joint, by a snatch block weighing about 45 pounds (16.7 kg.). His boat was in the harbor preparing to put to sea and the block, being used to hoist the anchor, was under heavy tension and flew about 10 feet (3 meters). After striking the patient, who was thrown 8 feet (2.5 meters) in the air, the block glanced off and struck a large galvanized iron bucket filled with sand. The impact was so great that it flattened the bucket. The patient was wearing a pair of high hip boots folded down in such a manner that the part of the leg struck was covered by about four thicknesses of rubber.

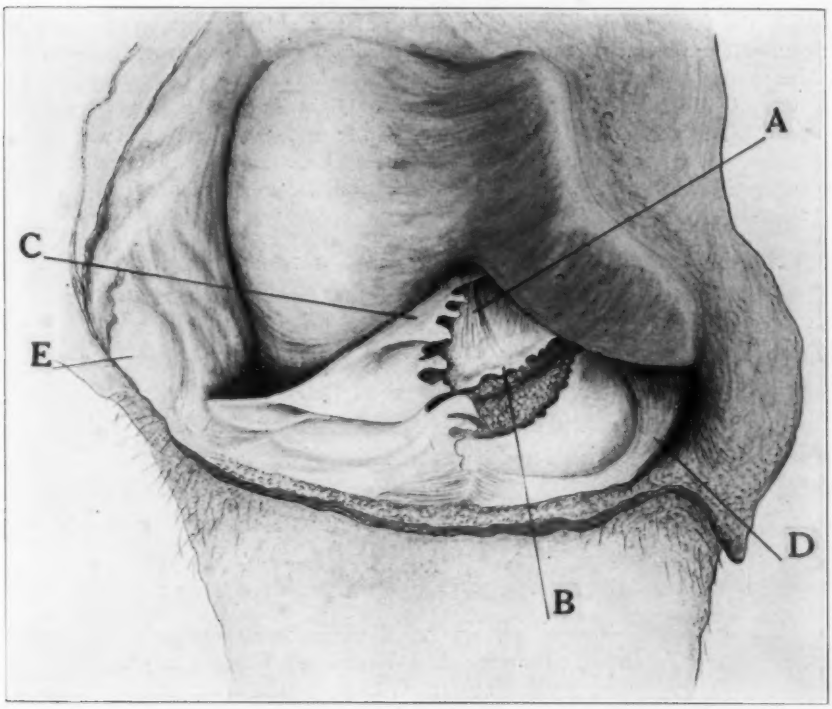

Fig. 4.—Experimental fracture of tibial spine as a result of tensile stress having been thrown upon the anterior crucial ligament using mechanism shown in Figure 3: (*A*) ligamentum cruciatum anterius; (*B*) detached tibial spine; (*C*) plica synovialis patellaris drawn to one side; (*D*) meniscus medialis; (*E*) reflected patella and ligamentum patellae; knee very strongly flexed.

For the moment, the patient was unconscious. The symptoms and treatment are not germane to the subject under consideration and will be omitted.

Roentgen-ray examination revealed a transverse fracture of the intercondylar spine of the left tibia in good position and with some excess callus.

The roentgenograms showed about the same condition as my own experimental case, of which I submit a drawing and roentgenogram (Figs. 4 and 5).

COMMENT

It is important to bear in mind the possibility of variation in the structure of the knee joint, for it may be the clue to differences between cases of injury when the mechanism is similar, and to explain discrepancies in reported clinical cases.

Fig. 5.—Roentgenogram showing an experimental fracture of the tibial spine; knee in extension; same as Figure 4; mechanism of production same as that shown in Figure 3; right knee, reversed in printing.

When stress on a joint is at variance with the optimum physiologic activity, injury is imminent, and the degree of such injury depends upon the relative mechanical advantage or disadvantage, plus the individual peculiarities regarding the relative strength of the several parts at the critical moment. The combination of factors attending each injury is, in all probability, never twice exactly alike.

The condition of loose-jointedness, in different degrees, may affect all or only a part of the ligaments of a joint. In the case of the knee joint the collateral ligaments being of normal or average length impart to the joint a firmness which we recognize as an optimum stability. Any deviation from this condition renders the joint liable to displacements when stress is exerted upon the crucial ligaments, unless the muscles acting on the joint respond in such a way as to supply the firmness that is lacking through looseness of the collateral ligaments. Again, the collateral ligaments may be of normal or optimum length or strength and the crucial ligaments, one or both, unusually relaxed, rendering the joint vulnerable to minor degrees of violence, as stress falls upon the collateral ligaments and indirectly upon the muscles that act on the joint.

These variant factors render the joint open to injury from less forcible stresses, and as the whole mechanism at the time of accident is a variable and complex quantity, depending upon the individual peculiarities and combinations of spasmodic muscular activity, it becomes an almost impossible task to determine the details of the mechanism in any case of injury. We must depend on an explanation as best we can.

Treves[1] states that from one surgical point of view, joints may be divided into three groups: (1) those that depend for their strength mainly upon ligaments; (2) those that are mechanically strong, and that derive their stability to a great extent from the arrangement of their component bones; (3) those that rely for their support principally upon muscles. The knee joint derives no strength from the shape of the articular surfaces, since they are merely placed in contact with one another, but from its ligaments and secondarily from muscles. In front is the powerful quadriceps extensor muscle of the thigh, the tendon of which acts as a ligament (ligamentum patellae) of the joint; posteriorly, the popliteus and relatively strong gastrocnemius of the sural group; medially, the semitendinosus, semimembranosus, gracilis and sartorius; laterally, the biceps.

In the ordinary activities of the joint, the ligaments are reenforced by these muscles, which are in a state of tonic contraction when the joint is functioning. Any deviation from an optimum combination necessary to the normal fulfilment of the physiologic requirements will render the joint vulnerable when stress falls in some particular way.

When sudden stress is thrown upon the joint as at the time of accident, whether it be a misstep, a slip, direct violence or the giving way of the surface upon which the person is walking, a sudden demand for quick and coordinate muscular action is necessitated to reenforce

the joint, if this is irregular and spasmodic and outside the usual action some one muscle acting in a relatively stronger way than normally, injury may follow.

Callender [5] says it is the "rule that bone gives way before fibrous tissue." It is evident that in the extended condition of the knee joint twists are without power (unless very violent) to cause injury. The condition is quite different when the joint is more or less flexed, as reported cases show. The biceps muscle by its power of external rotation plays an important part in the mechanism of resulting injury; or it may be the popliteus, semitendinosus, semimembranosus, gracilis and sartorius by their power of internal rotation.

Lange [4] calls attention to the relation between the crucial ligaments and the menisci (anterior crucial and medial meniscus; posterior crucial with the lateral meniscus), indicating that strains upon the crucial ligaments will be felt by the menisci and that dislocations of the menisci may be accompanied by sprain-fractures.

The facts, then, which must be taken into consideration when studying the results of injury to the knee joint are these: Allowances must be made for the different factors entering into the possible mechanism. The degree of force is at times not of sufficient moment to do much damage and yet internal injury may be present in the form of a mild strain or stretching of the soft parts; of sprain or sprain-fracture. Ross and Stewart [7] define the latter as "a condition resulting from an increase in tension on tendon or ligament, or from direct violence at the seat of tendinous or ligamentous attachment to bone. It is a separation of all or a part of that bone to which tendon or ligament is attached, from that bone of which it formed a part."

An analysis, then, of the foregoing, correlated with the results of the experiments already given with those of the clinical cases cited from the literature, permits of the following conclusions:

1. A strain is a stretching of the soft parts with a minimum amount of damage. It is not recognizable macroscopically, causing subjective symptoms.

2. A sprain is a rupture of the soft parts—ligaments or fasciae; recognizable by ecchymosis, loss of function and pain, the symptoms of which are both subjective and objective.

3. A sprain-fracture is, in the milder form, recognizable only by roentgen-ray examination; in the severer form it is recognized as a part of the pathology of dislocation.

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7. Ross, G. G., and Stewart, M. D.: A Study of Sprain Fracture, Ann. Surg. **55**:71, 1912.

In the milder form the crucial ligaments are involved, in combination with a strain or perhaps a sprain of the collateral ligaments, or injury to the menisci; in the latter both the collateral and crucial ligaments are involved, with different degrees of dislocation.

In experiments in which stress was thrown upon the crucial ligaments in an anteroposterior direction, with a little outward or inward thrust, the resulting injury, due to pull upon the crucial ligaments, demonstrated that one of three things might happen: (1) rupture or laceration of a crucial ligament; (2) fracture of the tibial spine, and (3) fracture of a femoral condyle by avulsion, through pull on a crucial ligament at the point of insertion. These three elements I shall call the crucial triad.

Dissections showed a minimum amount of damage to the collateral ligaments, with no objective evidence of injury. The roentgen ray demonstrated that a sprain-fracture was present.

Ross and Stewart [7] state that about 15 per cent. of all fractures are sprain-fractures. In the past many cases of fracture have passed unnoticed under the diagnosis of "severe sprain of the knee."

Preston [8] considers that fracture and avulsion of the tibial spine are due to pull of the crucial ligaments and are a complication of dislocation of the knee, and that avulsion of the spine occurs in lieu of rupture of the ligaments.

Stimson [9] says that avulsion of the tibial spine was known only as a complication of dislocation of the knee before the introduction of the roentgen rays, and says further that recently several cases have been recognized by aid of the roentgen rays in much slighter injuries of the knee joint, in the so-called sprains and twists. He refers to Lange's [4] article.

Robert Jones [2] states that rupture of the crucial ligaments and fracture of the spine of the tibia occur as the result of forcible twisting of the knee without sufficient displacement occurring for the case to be diagnosed as a dislocation of the knee.

The cases cited by Lange show that twisting of the knee played an important part in the mechanism of the injury, and demonstrate that sudden and severe strain to the knee joint is capable of producing injury within the joint, with negative evidence of bruising or any signs of fracture, not only in the cadaver but in the living subject as well. Lange calls attention to the fact that in his Case 3 the strain was borne chiefly by the crucial ligaments, resulting in avulsion of the spine

8. Preston, M. E.: Fractures and Dislocations, St. Louis, C. V. Mosby Company, 1915.

9. Stimson, L. A.: A Practical Treatise on Fractures and Dislocations, Ed. 6, Philadelphia, Lea & Febiger, 1910.

of the tibia. His Case 4 was complicated by the fact that the strain was apparently felt by the tibiofemoral collateral ligament which tore off its femoral (medial condyle) attachment. This was followed by stress on the crucial ligaments as shown by the injury.

In Callender's [5] case of the boy, 12 years old, who fell on some ice and struck his right knee a severe blow over the medial condyle, twisting his leg in his fall, final results showed avulsion of a fragment of bone from the medial surface of the lateral femoral condyle at the point of insertion of the anterior crucial ligament. Twisting played an important part in the mechanism of the injury in the three cases just cited. It is through this twisting that tensile stress in the direction of the longitudinal axis of the anterior crucial ligament is brought about.

It makes no difference whether the femur is carried forcibly backward and a little outward, or whether the tibia is carried forcibly forward and a little inward with twisting, for under the remarks on surgical anatomy it was stated that in flexion the tibia rotates inward, and when this occurs under sudden stress with the leg undergoing flexion, sudden and heavy stress is thrown upon the anterior crucial ligament, for it is probable that the tibia moves forward as well as rotates inward. It has been stated above that the whole mechanism of injury is variable and complex, depending upon the individual peculiarities and combinations of irregular muscular activities, so that it is impossible to determine the details attending the accident. These activities modify the results of pure violence in manifold ways.

The case cited by Ross,[6] and quoted above, regarding the ensign on the U. S. S. *Douglass,* agrees in a most gratifying way in illustrating that force applied over the upper and back part of the leg, driving the tibia forward, as demonstrated in the experiments given above, will produce fracture of the tibial spine. Even the pad was present in the folded top of the rubber boot. The exact details of the mechanism of production are not known as is always the case.

The consideration of the foregoing cases is sufficient to prove to a certain extent, at least, my findings in experimental work.

SUMMARY

The foregoing résumé and results of experimentation appear to warrant the following statements:

1. Variation in the anatomic constituents of a part must be considered. These affect size, strength and length, and are often a part of a peculiar body habitus.

2. Variations in anatomic structures may predispose the individual or part to injury from less forcible degrees of stress than are ordinarily capable of producing such injury in parts of optimum stability.

3. Injuries to the knee joint which may appear slight or trivial are occasionally accompanied by a crucial triad involvement.

4. All injuries to joints should be considered seriously, not only for the sake of possible strain, sprain or sprain-fracture, but as forming a point of least resistance.

5. Sprain-fracture of the knee joint may be present without giving objective symptoms. Roentgenograms reveal the fracture.

6. Rupture of a crucial ligament may be present without giving objective symptoms, except as stated under paragraph 16, and is not shown by roentgenograms.

7. Experimental fractures of the spine of the tibia agree closely in character and mechanism of production with actual clinical cases.

8. Sprain-fracture or rupture of ligaments occurring consistently in experimental procedures on the cadaver afford the most positive proof of the fact that injuries are permitted to occur in this way; failure to demonstrate such injuries in experimental tests on cadavers means nothing (Ross).

9. Experiments on the cadaver have demonstrated that force applied over the distal and anterior surface of the thigh (femur), driving the femur backward on the tibia when the leg is fixed, will produce rupture of the anterior crucial ligament (greater force rupturing both crucials), and fracture of the tibial spine anteriorly or avulsion of a fragment of bone from the femoral condyle at the point of insertion of the ligament, resulting in crucial triad involvement.

10. Experiments on the cadaver have given direct proof that similar results may be obtained when the tibia is driven forward by force applied to the upper and posterior part of the leg, driving the tibia forward on the femur, the thigh being fixed.

11. Inward rotation of the leg (tibia), when it is more or less flexed, may result in injury to the lateral meniscus or may involve an element of the crucial triad.

12. Inward rotation of the leg may be accomplished by direct action of the muscles (sartorius, gracilis, etc.) or by mechanical violence.

13. Outward rotation of the leg (tibia), when it is more or less flexed, may lacerate the medial meniscus, or involve an element of the crucial triad.

14. Outward rotation of the leg is accomplished by action of the biceps femoris muscle, or by mechanical violence.

15. Violence applied laterally to the knee results in a complicated injury—fracture of femoral condyles, tibial tuberosities or fibular head, crucial triad involvement, with dislocation of the knee in any degree according to the character of the violence.

16. When, after an injury to the knee, it is found that the tibia can be displaced backward or forward, or rotated inward in the extended position, an injury of one or both crucial ligaments may be diagnosed. Such patients complain of preternatural mobility and insecurity in the knee (Robert Jones [2]).

17. When in the extended position the tibia cannot be displaced forward, it may be assumed that the anterior crucial ligament is not torn across. If in full flexion the tibia cannot be displaced backward, the posterior crucial ligament is not ruptured (Robert Jones [2]).

18. It should be borne in mind that no two injuries are exactly alike, either in pathology or in mechanism of production; that the results are the outcome of complicated interactions at a critical period of time, of external violence, individual peculiarities and complex spasmodic muscular actions, and that diagnostic statements are but guides to individual deductions in each particular case of injury that is of clinical interest.

OBSERVATIONS ON THE CORRECTIVE AND OPERATIVE TREATMENT OF STRUCTURAL SCOLIOSIS *

ARMITAGE WHITMAN, M.D.

NEW YORK

In summarizing three years' experience in the treatment of structural scoliosis of unknown cause, it has seemed best to begin with a short discussion of scoliosis in general, and of the theory and practice of its treatment, in order to make clear the gradations which finally led to the introduction of the operation. It must be understood that the experiences on which these remarks are based are, with one exception, those of hospital practice. If the subject of scoliosis appears to be taken seriously, it is because the cases I have seen are serious and are so regarded by the patients themselves.

Among the most discouraging subjects with which orthopedic surgeons have to deal is rotary lateral curvature of the spine. It is not necessary in an article of this character to make an exhaustive catalogue of its well known causes. The most common and important are various diseases of the nervous system, rickets, empyema, torticollis, and vertebral malformations. Less common are inequality in the length of the legs, astigmatism, general muscular insufficiency—in general, anything which affects the balance or symmetry of the body.

Aside from these cases, to which a cause may definitely be assigned, there remains a large and extremely important class in which I am particularly interested: scoliosis of unknown origin, or, to use a term which I shall employ for the sake of brevity, "idiopathic scoliosis."

There have been many theories advanced as to the etiologic factor in this group. Some believe it to be unrecognized anterior poliomyelitis; others, malformations of the fifth lumbar vertebra; and still others, slouchy posture, or the persistent assumption of a faulty attitude.

I have examined all the cases in this series for evidence of anterior poliomyelitis, and have not found it. In cases in which scoliosis is definitely caused by this disease, it is originally overlooked because the unilateral abdominal paralysis, or weakness, which is usually its cause is not sought for by a methodical routine examination, and often escapes attention. It may, however, subsequently be demonstrated if present.

Malformations of the fifth lumbar vertebra have not been observed. No two surgeons can be found who will agree as to what the roentgenographic appearance of a normal fifth lumbar vertebra should be. Aside

* From the Hospital for the Ruptured and Crippled, service of Dr. Royal Whitman.

from this difficulty, however, there is the theoretical objection that a curvature arising from such a source should be the response to a constant variation, and that, the source remaining the same, the variation should proceed to a point of compensation and there cease. I think that no one would venture to say with certainty when a given case of scoliosis had arrested its progress.

All authors mention undernourishment, poor muscular tone, slouchy attitude; in other words, the physically sloppy persons, as being typical subjects of the deformity. Oddly enough, however, I have not observed

Fig. 1.—Left, back before treatment; right, side view before treatment.

this to be so. All girls nowadays are under the influence of the débutante slouch, the attitude in which the abdomen becomes the most prominent feature. The patients in my series, as will be seen from their photographs, were neither particularly sloppy nor particularly weedy.

All that we are entitled to say of this class of cases, therefore, is that girls are evidently far more commonly affected than boys, and, as it is very uncommon in quadrupeds, that it is probably largely a fault subsequent to the assumption of the upright attitude.

The type of patient with whom we are dealing, then, is a girl between the ages of 12 and 16 years, presenting a fixed, or structural scoliosis,

a deformity which cannot be corrected by a change of attitude, and in which the normal structure of a vertebra, or vertebrae, has already been altered. We are dealing, therefore, with a condition of whose origin we are practically ignorant, and of whose course in a given case we are uncertain.

VARIOUS CORRECTIVE METHODS

Since the time of Hippocrates, various methods of correction have been attempted: exercises, and apparatus applied with the patient suspended, with the patient prone, with lateral traction, and with direct pressure on the ribs. Dr. Abbott, at length, introduced an important variation in that he worked on the principle that the spine was more easily rotated—untwisted—in the attitude of full flexion, when the articular processes were thus separated as far as possible. Once the rotation was corrected the straightening of the lateral deformity would be easy. He also emphasized the necessity of maintaining overcorrection until accommodative changes in the spine had taken place. In practice, at least in the experience at the Hospital for the Ruptured and Crippled, this did not prove as simple as it sounds. The patient was often sacrificed to his curvature; and the secondary deformities, muscular atrophies and pressure sores resulting from the corrective jackets might leave the last state of the patient worse than the first.

The insuperable obstacle to efficient treatment of this deformity is that in any ambulatory treatment we are forced to attempt to straighten a tree by applying pressure to its branches. There is another horticultural principle in the background: a growing plant, such as a cucumber, introduced into a vessel, will in time, with the process of growth, adapt itself to the shape of the vessel. In other words, applying straight plaster-of-Paris jackets to a growing body will in time induce the body to grow straight.

We are hampered by the fact that the deformity to the average patient does not present itself as a condition requiring surgical care and that its treatment must be confined within those limits to which the patient will consent. In the majority of cases it must, therefore, be ambulatory.

In the cases in question, however, there has been one point favorable to the success of the treatment, namely, that the patients, between the ages of 12 and 19, came to the hospital voluntarily because they were concerned about their unsightly appearance, and therefore they did not have to be browbeaten or persuaded to undertake a treatment of considerable severity.

As a reaction against the unpleasant secondary effects of the Abbott treatment, Dr. Whitman suggested the application of plaster-of-Paris jackets with the patient suspended, and in full extension and rotation.

Fig. 2.—Patient suspended, heels just touching ground; showing preliminary felt padding and direction of pull of traction bands.

This treatment has gradually been modified and the rotation largely given up. The jacket is now applied with the patient suspended, in full extension, with traction, and pressure over the protruding ribs. A large window is cut out over the hollow side, to encourage the expansion of the chest. The high shoulder is included in the plaster to hold it

Fig. 3.—Preliminary padding, showing band pulling in oblique direction directly against convexity of ribs; also assuring hyperextension of spine.

down and the plaster carried as high as possible under the arm on the low side to throw the body in the reverse direction. The patient is never allowed to stand or sit unsupported, even when the jackets are being changed.

Fig. 4.—Jacket applied.

The full details of the application of this type of jacket are presented in Dr. Kleinberg's article.[1] One modification of the treatment he describes has been introduced. I have had a third upright added to the frame in which the jackets are applied. This bar moves from a fixed point midway between the other two and may thus be placed at

Fig. 5.—Jacket applied.

any point on the circumference of a half circle. By this means, the traction is made on a line directly antagonistic to the point of greatest curvature of the ribs. It also aids considerably in assuring hyperextension of the spine.

1. Kleinberg, S.: Scoliosis, Surg. Gynec. & Obst. **32**:364 (April) 1921.

Dr. Lovett [2] objects to suspension on the ground that no one attempts to straighten a bent stick by pulling on its ends, and that the greater the tension thus produced, the more ineffective must be any attempt at lateral bending. On the other hand, no one would be condemned for trying to straighten the warped shaft of a golf club by hanging it up in a moist atmosphere with a weight on its end. These considerations are more or less theoretical. Practically, however, we have experienced an objection to the application of jackets in the prone position, in that they are likely to be exceedingly uncomfortable, and to necessitate the patient's lying down at frequent intervals. We consider the advantage of the present method to be that, up to the final stage, the treatment is entirely ambulatory.

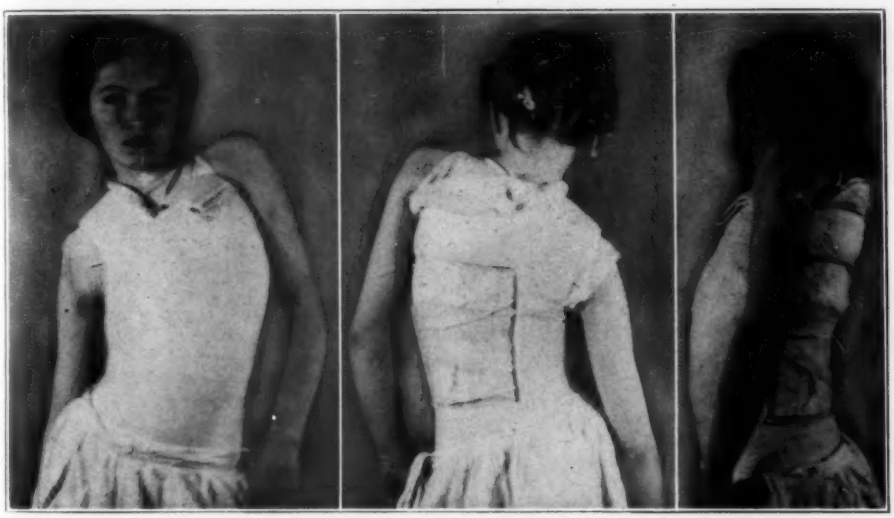

Fig. 6.—Left, completed jacket; center, showing extent of fenestrum, elevation of low shoulder, complete obliteration of original convexity on the right side; right, side view.

Although theoretically, and in accordance with the experiments of Dr. Lovett, the spine is perhaps locked in extension, clinically we have by this means succeeded in considerable correction of the curvature, as shown by the roentgen ray, and, what is more important, in great improvement of the external appearance of the trunk, the matter about which the patient herself is chiefly concerned. One patient, coming from West Virginia, and thus at a disadvantage as regards supervision, found the treatment exhausting, lost weight and was forced to abandon it. The others have gone about their ordinary pursuits, and in most cases their general condition has noticeably improved. The gain in height and the improvement in color and complexion have been striking. The

2. Lovett, R. W.: Lateral Curvature of the Spine and Round Shoulders, Philadelphia, P. Blakiston's Son & Co, 1907, p. 129.

jackets are changed at intervals of two months. There has been one small pressure sore, which did not necessitate the removal of the plaster.

The use of the corrective jackets is kept up, naturally, as long as correction of the curvature, as shown in the roentgenogram, is seen to be progressive. In one case, of a long single curve, the condition has been fully corrected. Here let me emphasize, however, that "fully corrected" means simply that, according to the roentgenogram, the lateral curvature of the spine has been corrected. Anatomically, I doubt whether the rotation has been at all affected, except as it is influenced

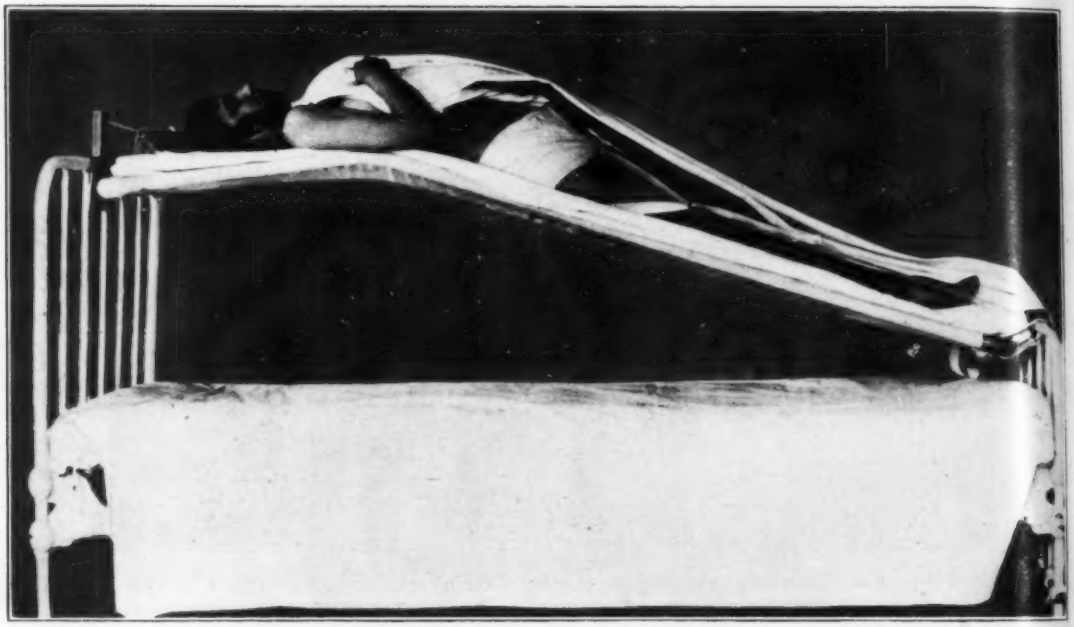

Fig. 7.—The convex stretcher frame, with traction on the head and pelvis, used before and after operation.

by the extension, and I believe that the external improvement in the appearance of the trunk is due simply to the lengthening of the spine and to the pressure of the jacket on the more or less elastic ribs.[3] Usually, however, the typical right dorsal curve will improve up to a certain point, and there remain, further attempts at correction causing only exaggeration of the curves above and below it, which is useless and undesirable.

3. Dr. Kleinberg tells me that he has observed by the roentgen ray apparent complete correction of the rotation in two cases. In both of these cases there was subsequent relapse.

THE FUSION OPERATION

One is then faced with the problem of what to do next. If a straight jacket, removable plaster corset, or a brace is applied, the patient will relapse to a greater or less extent. The correction of the spine can be maintained only by the jacket, applied in the deforming attitude, which is repugnant to the patient. The prospect of wearing

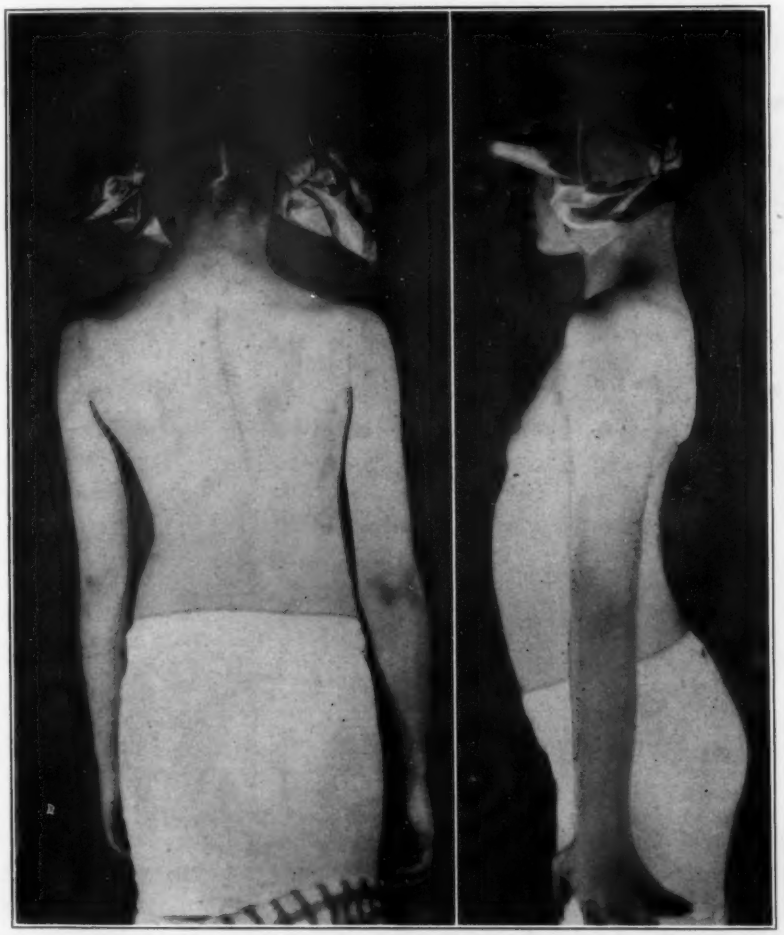

Fig. 8.—Left, back four months after operation; right, side view after operation.

apparatus for from two to four years, while the accommodative changes in the spine take place, is not alluring. In seeking an exit from this situation, I became interested in the fusion operation on the spine, as performed by Dr. Hibbs. The method has also been resorted to by nature in cases of spinal caries.

Theoretically, the argument for the operation would be this: We may assume, except in the case of curvatures developing from perfectly well known causes, and in cases of long single curves, that there is originally a primary curve, in response to which, in order to maintain the balance of the body, a secondary curve develops. If we can, by any means, check the progress of the primary curve, the secondary curve should have no excuse for progressing. Also, by providing a certain area of stiffness, one might facilitate muscular control, on the principle that it is easier to balance a stick than a rubber tube.

On the basis of this theory, then, the operation was proposed. Curiously enough, the first patient was the sister of a girl who had been

Fig. 9.—After operation, patient bending forward to show the obliteration of the convexity of the ribs.

treated at the hospital by the Abbott method for four years, absolutely without success, and had eventually developed the most extreme deformity. She was, therefore, alive to the importance of her condition, and peculiarly intelligent as to the rationale of treatment. It was explained to her that the operation was a new departure, at least at the Hospital for the Ruptured and Crippled (and I believe Dr. Hibbs and Dr. Forbes have confined themselves to cases of paralytic origin), and entirely experimental in character. She was told that the spine having been corrected up to a certain point and the external symmetry of the trunk practically restored, the operation was performed for the purpose of internal, rather than external, splinting, to maintain the degree of

correction. In other words, it was a choice between operation and the wearing of a brace, jacket or corset for between three and four years.

The operation was performed in June, 1920. The patient was then placed in a plaster shell, and two weeks later a corrective jacket was applied, which she wore home. Unfortunately, the correction was a little too successful, in that, when the spine stiffened, it maintained the elevation of the previously low shoulder, although no such correction can be seen in the roentgenogram. This, however, is not evident on casual inspection, and is of no importance. Plaster jackets were worn for four months after the operation. Since October, 1920, the patient has been without support. The dorsal spine appears stiff; there has been no appreciable increase in the deformity, either externally or roentgenographically; the patient looks well, and is satisfied with the result. Her influence has been strong in urging other patients to submit to operation.

Since July, 1920, I have operated on fifteen patients, and the routine of treatment and the details of the operation have been varied. It is now the practice, on removal of the jackets, to place the patients on the convex stretcher frame for a few days previous to the operation, to allow them to become accustomed to the frame, and to provide opportunity for thorough cleansing of the skin. Following the operation, the patient is placed directly on the frame and there remains for two months. As soon as the postoperative discomfort has subsided, traction is applied to the head and pelvis, gradually increased to as much as 20 pounds (9 kg.) on the head and 30 pounds (13.6 kg.) on the pelvis. I do not feel that the traction is of any particular importance except as a means of assuring the immobility of the patient. The frame itself assures hyperextension of the spine, the position in which residual deformity, if present, is least evident, and encourages chest expansion; and the pressure of the body weight is of service in reducing the protrusion of the ribs. We have also lately, both before and after operation, applied traction in an anterolateral direction against the convexity of the ribs in the manner employed during the application of the jackets. This seems to be of real service in reducing the apparent deformity.

The operation is, as a rule, accompanied by considerable shock, depending a great deal, of course, on the time consumed in performing it. This has varied from an hour to an hour and three-quarters. The patient's position places the anesthetist at a disadvantage. In two cases, it has been necessary to remove the patient from the frame during the night following the operation. One can think of no theoretical reason for this removal, but practically putting the patient in his accustomed environment—bed—seems to sooth and reassure. There have been no deaths and no infections.

I have been surprised at the lack of pain following the operation. I discovered one patient, on the eighth day, turned on her face, propped on her elbows and conversing with a visitor. I was at first troubled by the amount of movement permitted on the frame, but have lately solaced myself with the idea that, as asserted by the advocates of the treatment of fractures by traction and suspension, a certain amount of movement might tend to an exuberant callous formation. It is my impression that the patients on the frames have stiffened more quickly than the ones who were placed at once in plaster.

The patient remains on the frame for two months, by which time stiffness of the area of operation seems established. A short straight jacket is then applied, to maintain the balance of the trunk, and to prevent the area of operation from being subjected to any strain, in the same way in which one would wish to protect a fractured femur for some time after bony union appeared firm. This jacket is worn for about two months. Some patients are then able to go without any support whatever. In others, it will be found that the long period of external support and inactivity of the spinal muscles, usually about eighteen months, has so weakened the area untouched by operation that the patients suffer considerably from weakness and backache. In such cases, we apply a brace or corset, and institute graduated exercises for the weakened muscles.

The operative technic has been gradually worked into a combination of the Hibbs and Forbes operations. The periosteum is carefully removed, and a thorough attempt is made to destroy the intervertebral articulations, as in the Hibbs operation. The laminae are then more roughly treated than in Dr. Hibbs' procedure, several sections of bone being pried up on each side. The spinous processes are split horizontally and vertically, and bent upward and downward, providing very satisfactory interdigitation. The ligaments are united with chromic gut. I must say that the variations in the operative technic have been caused by the inward promptings of the operator who wished to perform as apparently thorough an operation as possible, rather than by any unsatisfactory results from either of the original technics.

CONCLUSIONS

This treatment, it will be seen, develops as the result of a discouragement with all previous methods. Its effect, by providing opportunities for observation on the exposed spine, has been more discouraging still. I have found in backs in which, according to the roentgen-ray examination, the lateral curvature was almost, or entirely, corrected, a surprising degree of rotation persisting. A patient of 14 years, under treatment for more than a year, in whom the deformity had been noticed only a few days before admission to the hospital, had, at operation, a very marked

rotation and distortion of the vertebrae. Force sufficient to fracture a spinous process has been applied on several occasions without having the slightest effect on the rotation, and that following removal of all the posterior ligaments of the spine, with the patient prone and anesthetized. How, then, may we expect, anatomically, to correct deformity of the spine by any ambulatory treatment, and when all the force we are able to exert can be applied only to the ribs? It is conceivable that prolonged rest on the stretcher frame might correct the deformity, but I can conceive of no patient who would submit to such an indefinite prolongation of recumbency.

This experiment might be of interest in connection with the operation proposed in January, 1894, by Dr. Shaffer,[4] who suggested operating in early cases, by severance of the costotransverse ligaments and any other opposing structures; then, by actual instrumental force applied to the transverse processes, reducing the malposition of the vertebrae, a procedure which he evidently considered analogous to a subluxation.

Neither can I agree with the conclusions presented by Dr. Hoke,[5] who believed that by removal of a section of the ribs, first on one side and then on the other, he might more easily, by force, correct the malposition of the vertebrae. According to his published case, he did succeed in improving the external appearance of the thorax, but whether any alteration in the position or structure of the vertebrae was accomplished is doubtful. This opinion is sustained by the fact that I can find no further reference to the operation since Dr. Hoke's original article appeared, in 1903.

I will not even say that I am sure that ankylosis has been obtained in every case. I think it has, but the difficulties of judging of movements of the dorsal spine are so great that the presence or absence of motion must rest largely in the desire, subconscious or otherwise, of the examiner. Sufficient stiffness, however, has been obtained to limit forward bending, and thus to conceal the protrusion of the ribs, the most objectionable feature of the deformity. There has, so far, been no increase in the deformity, either as shown by roentgen-ray examination, or in the estimation of the patient. One may mention also that there can be no class of cases in which the opinion of the patient is of more value. The patients apply for treatment because they are concerned about their unsightly appearance, and there can thus be no keener critics of the cosmetic effect. It is unfortunate that neither necropsy nor second operation has provided opportunity actually to inspect the result.

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4. Shaffer: Am. Med.-Surg. Bull., Jan. 1, 1894, p. 51; Feb. 15, 1894, p. 235.
5. Hoke: Am. J. Orthop. Surg. **1**:169, 1903.

Judgment of the existence of ankylosis by the roentgen ray is unsatisfactory and misleading. A good lateral picture will sometimes show the continuous bridge of bone formed by the fractured spinous processes, but anteroposteriorly one sees nothing except obliteration of the facets of the articular processes and slight obscuring of the intervertebral disks. Naturally, one would not expect them to be altogether invisible, as no bony deposit could be as thick as the vertebral body.

A discouraging feature of the deformity is the fact that the side of the chest on which the ribs project is already the narrow side, and that pressing on the ribs to reduce obvious deformity makes the chest narrower still. This is a disadvantage which is somewhat alleviated by the frame treatment, in which the chest has every opportunity to expand.

The three years' work in the treatment of rotary lateral curvature of idiopathic origin has thus resulted in a curious mixture of optimism and pessimism. I am convinced that the anatomic cure of the deformity by any means hitherto devised is impossible. A certain proportion of fairly well advanced cases, particularly of long single curvatures, may be markedly improved in external appearance, and their curvatures, as revealed roentgenographically, much reduced by the type of jacket we are now applying. It seems that the degree of improvement thus acquired might be maintained by some type of fusion operation in the area assumed to be that of the primary curve. The objection may be advanced that the cases are too recent to be judged as end-results; but, on the other hand, the patients have practically all attained full growth, so that future development cannot have much influence on their course; and surely one would expect that, if the deformity were to progress, its progression would be most rapid immediately following the removal of the jacket, in the period when the security of the fixation is most doubtful and general weakness and muscular atrophy are most extreme.

The treatment is not one which will ever be applied to a large class of patients. It is somewhat exhausting to both patient and surgeon. It requires of the patient to an extraordinary degree the development of the "will to get well," and of confidence in the person conducting the treatment. It requires of the surgeon the knowledge, primarily, of what cases are susceptible of improvement by the treatment; the skill and experience necessary for the application of the corrective jackets; the persistence to apply them personally during long periods, and, finally, the acquisition of the rather difficult technic of the operation.

I am not in sympathy with the attitude of surgeons who publish reports of most difficult operative procedures, the results often of years of specialized effort on their part, and convey the impression to the casual reader that the reading of the article fully equips one for the performance of the operation. Such writers would privately admit that

such an impression was conveyed for the purpose of flattering the intelligence of their readers, but it seems surprising that they should esteem an audience of such implied intelligence worthy of the pains.

It is to be hoped that no wave of enthusiasm will develop for the "operative treatment of scoliosis." It must be emphasized that the operation is the final step in a tedious process of correction, and that in principle it offers little that is new, unless it be the principle of balance on which it is performed. It must not be urged on the patient. In fact, throughout this kind of treatment, it is essential that the patients themselves be desirous of treatment. Such severe measures as are necessary cannot and should not be forced on an unwilling child. For an orthopedic surgeon to mention psychology will doubtless be provocative of more or less indulgent mirth, but none the less it is the most important factor in any form of treatment for scoliosis. The surgeon may labor with the body of a patient as much as he pleases, and obtain a physically good result, but unless he can persuade the mind that to stand up straight is desirable, his work will be a failure. There is no spine so crooked that its appearance cannot be improved by effort on the part of its owner; and, conversely, there is none so straight, artificially or otherwise, that it cannot by slouching be made to simulate deformity.

One is continually impressed by the futility of many conventional forms of treatment. Of what use are exercises for scoliosis if the patient slouches to and from the gymnasium? Of what use are exercises in the treatment of weak feet if the patient walks with his toes turned out? After all, the business of any mechanism is to function, and the function that is important is that involved in the ordinary occupations. The purpose of the foot is to make walking possible, not to be educated muscularly before a mirror. This factor, the mental control of a patient, is the essential one in any treatment involving anything except the giving of pills. Even pill giving, a regimen of comparative simplicity, may be a failure without the supervision of a third person.

No one regrets more than I the absence of the original photographs and roentgenograms of so many of the patients. I can only ask those who are acquainted with the trials of work extending over long periods of time to remember the facility with which roentgenograms and photographic plates are broken and lost. As no extraordinary claims are made, perhaps the absence of these important records is not of so great importance as it otherwise might be. Photographs may be easily disparaged as records in any case, as we all know how shadows and focal lengths may be manipulated to the advantage, or disadvantage, of the record. I requested the roentgen-ray department to make the photographs in standard poses and at the same focal distance, but was not present when any of them were taken. Trivial as some of the original

deformities may thus appear, to the patients their appearance was sufficiently repugnant to make them submit to months of plaster, operation, and, finally, two months on a stretcher frame.

It has been suggested by some casual observers of these patients that none but mild cases have been selected for operation. This is not altogether true, but there is foundation for the suggestion. As has already been stated, the operation is only the final step in the course of a long process of correction. The patients were not selected with a view to their being operated on, but because it was thought when they first presented themselves that their curvatures were susceptible of improvement by corrective jackets.

In this series there is one case of extreme deformity in which operation was performed in the hope that the stiffening of the spine would relieve the pain and act as a substitute for apparatus. Unfortunately, this is the only one in which the end-result is not known. Four of the fifteen cases are too recent to report. The detailed report of eleven cases follows. Notes other than those made by me are followed by the name of the physician supplying them.

REPORT OF CASES

CASE 1.—*History.*—M. M., aged 14, schoolgirl, was admitted to the outpatient department of the hospital, April 29, 1920, with a history of measles, varicella, mumps, pertussis and influenza. The parents and brothers were healthy. The chief complaint was lateral curvature of the spine, of possibly three months' duration. The scoliosis was first observed by the school nurse about three months previously. It was noticed that the patient walked and sat with the right shoulder elevated, and was unable to throw her shoulders backward. On examination, the lateral curvature was found. Roentgen-ray examination was made, April 6, 1920. The rectal temperature was 99.4 F. A throat culture was taken (B. L. Schoolfield).

Physical Examination.—May 1 (Dr. Whitman): The patient was in fair condition. She presented a moderate double curvature of the spine, most marked to the right in the dorsal region. There was compensatory deformity with but little rotation in the lumbar region. Instructions were given that a roentgenogram and photograph be taken and a corrective jacket applied.

Treatment.—May 11: For the past forty-eight hours, the patient had been on a frame with 5 pounds (2.2 kg.) traction on each leg, and 10 pounds (4.4 kg.) on the head. The dorsolumbar curve and the very marked rigidity of the spine had almost disappeared, but there was now evident a very sharp, practically right angled, curve to the right between the second and fourth dorsal vertebrae. A roentgenogram embracing the seventh cervical to the fifth dorsal vertebra was made. The only discomfort caused by the treatment was redness and soreness under the chin, a difficulty which may be obviated by the use of a little extra padding.

May 13: The head sling had been applied in a new manner by Dr. Kau. One strap now passed over the forehead, the other behind the ears and was attached under the occiput. The patient was comfortable with the strapping applied in this manner.

May 18: The second roentgenogram revealed a very marked wedging of the third dorsal vertebra and malformation of the second and third ribs on the right side in the nature of an articulation between the two, about 1 inch (2.5 cm.) distal to the point of articulation with the vertebrae. It was suggested that this malformation might be responsible for the curvature. But a week later Dr. Whitman stated that, in his opinion, the malformation of the ribs had nothing to do with the patient's curvature.

May 27: The deformity of the spine had decreased.

Operation.—June 5 (Dr. A. Whitman; assistant, Dr. Purdy): An incision was made from the seventh cervical to the sixth dorsal vertebra, and the usual procedure of the Hibbs operation carried out. Considerable difficulty was

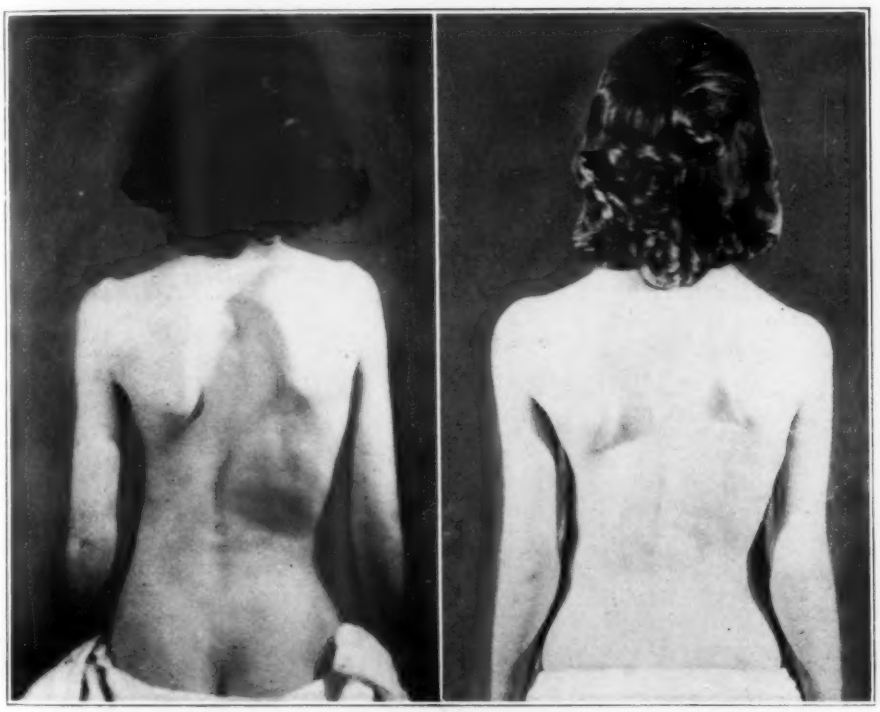

Fig. 10 (Case 1).—Left, before operation; right, after operation.

experienced with oozing. At the level of the fourth dorsal vertebra on the right side, a pin point perforation of the pleura occurred. The muscle was at once allowed to fall over it. When the packing was removed ten minutes later, in order to finish the operation, there was no escape of air. No shock was noticed from this accident. The ligamentum nuchae was united with continuous plain gut. The skin was closed in the usual manner and a Calot jacket, which had been applied previously and cut off, was reapplied.

After-Treatment.—June 17: The patient had a rise in temperature of 2 degrees following the operation, but no pain. Five pounds (2.2 kg.) traction on the head and 19 pounds (8.6 kg.) on the legs was applied about two days after the operation. There was no discomfort.

June 17 (p. m.): On removal of the shell, the wound was cleanly healed. With extension on the head and feet, the patient was suspended in bed by two bands of felt passed beneath the shoulders and hips and the Calot jacket was applied. A roentgenogram was made.

July 8: A second Calot jacket had been applied, July 6. The external appearance of the child's trunk was very good except for a slight prominence of

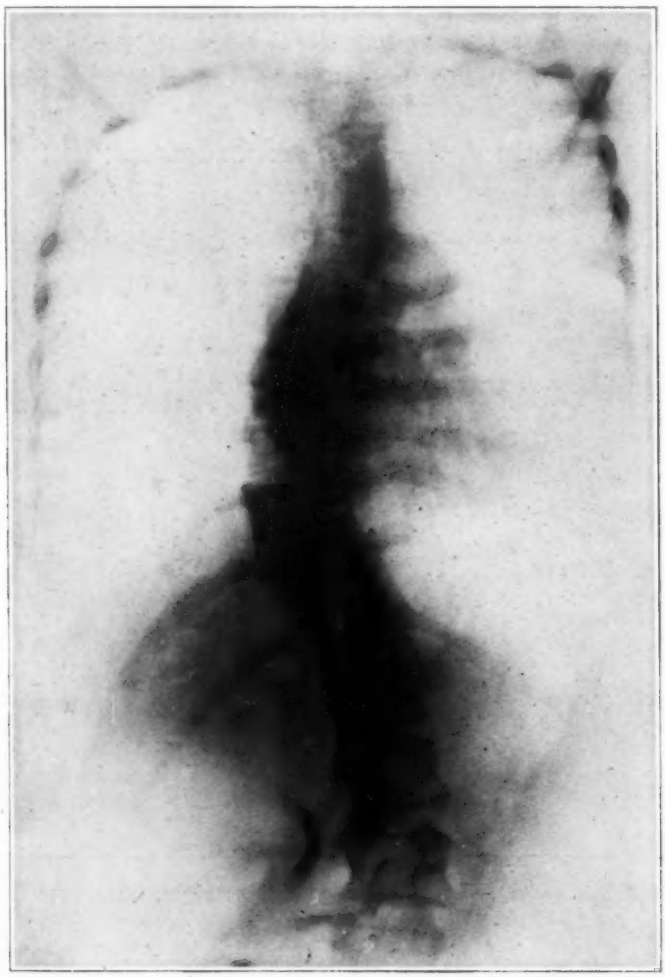

Fig. 11 (Case 1).—Before operation. All the cases are right dorsal curves with the exception of Case 3.

the ribs on the right side. The spine in the region of operation appeared to be almost stiff.

July 8: The patient was discharged improved, and wearing a Calot jacket, with instructions to return August 5.

Readmission.—September 7: The patient reentered the outpatient department.

September 11: The Calot jacket was removed. There was marked atrophy of the muscles of the back and intrascapular region. The spine in the region of

operation appeared perfectly stiff. Dr. Whitman and Dr. Kleinberg concurred in this opinion. Instructions were given that the child was to lie in bed and have gentle massage of the back muscles. A roentgenogram was made.

September 18: The roentgen ray revealed marked indistinctness of the intervertebral disks in the region of operation. The field of operation still

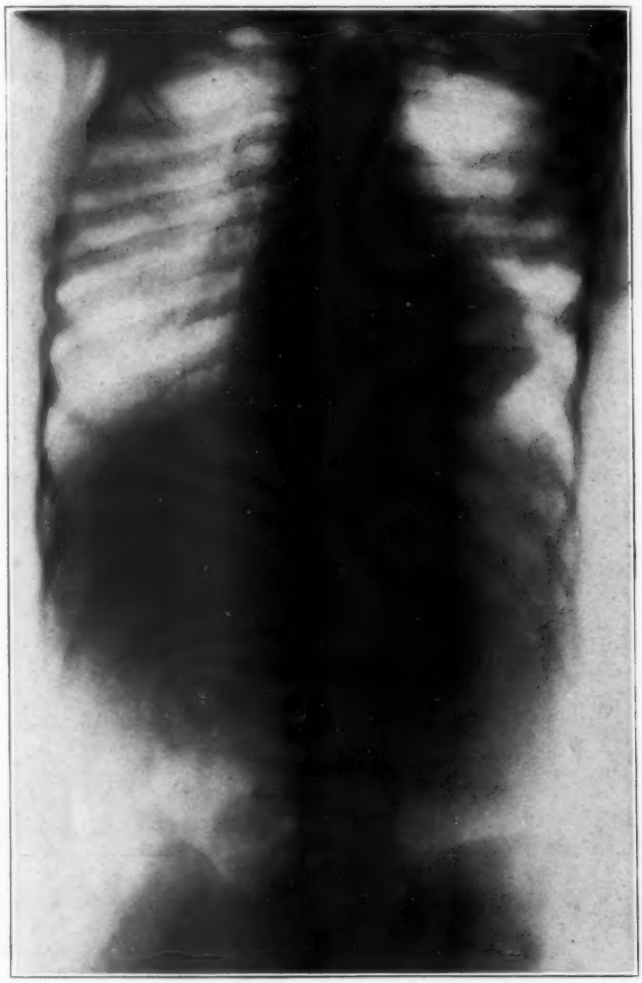

Fig. 12 (Case 1).—After operation.

appeared perfectly stiff. The patient was discharged, with instructions to return in two weeks (October 2) for observation.

She was improved, and on discharge was without apparatus or plaster.

Subsequent Course.—October 9: The child had been at home three weeks, going to school. She lay down during the noon hour, and took no exercise in the gymnasium. She was perfectly comfortable, and the spinal muscles had

greatly increased in size and tone since the last report. No movement was discovered in the area of operation. A roentgenogram and photograph were taken.

March 17 (Dr. Whitman): As far as could be made out, the spine was rigid in the area of operation. The hips were of equal prominence; the shoulders level. There was still a prominence of the right scapula and a compensatory curve to the left in the lumbar region. It was the opinion of the patient, the supervising nurse and the family that the deformity had not increased since operation. A roentgenogram and photograph were taken.

April 22, 1922: The patient was in good condition. There was no increase of deformity.

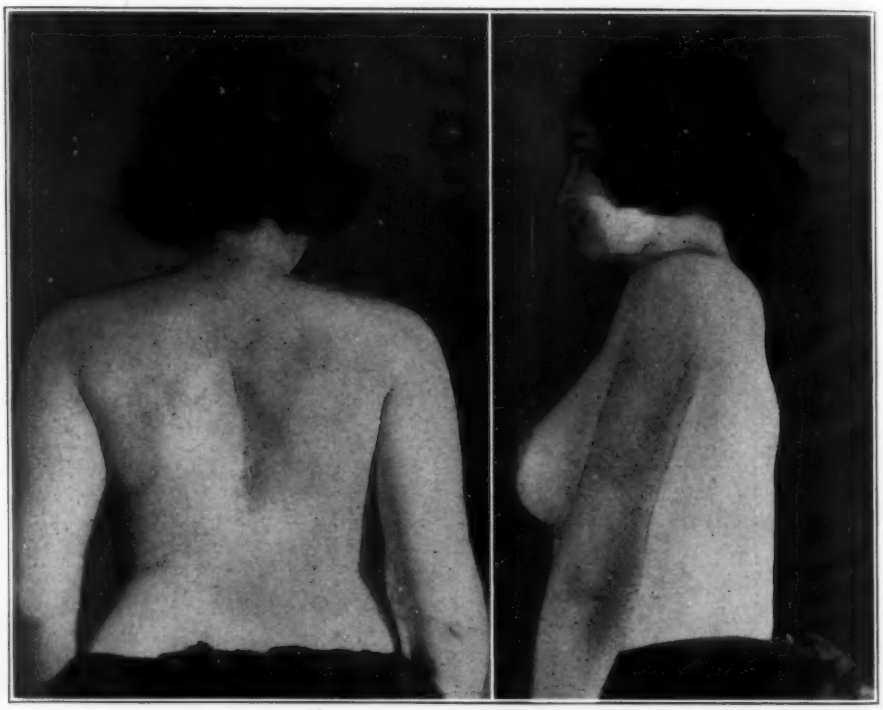

Fig. 13 (Case 2).—After operation.

CASE 2.—*History.*—I. P., girl, aged 14 years, had two brothers living and well; one sister with lateral curvature. Two brothers died in infancy, cause of death being unknown. The mother had had no miscarriages, and there was no tuberculosis in the family. The chief complaint of the patient was rotary lateral curvature, of fifteen months' duration. It was first noticed when the patient was being fitted for a dress, the summer of the preceding year, that the left hip was more prominent than the other, and the right shoulder was the higher. No angulation was noticed at this time. There had been no known poliomyelitis. The curvature was slight, right dorsal, when first noticed. It had progressed, and the preceding summer, angulation was first seen. The

patient had been under the care of Dr. Kleinberg since the onset, taking exercises, but no cast was applied. The only symptoms were fatigue on slight exertion and severe pain in the region of the right scapula, not radiating.

Physical Examination.—Nov. 1, 1919 (Dr. Whitman): The patient was in good condition, rather fat and heavy. She presented a marked fixed rotary lateral curvature involving the dorsal and lumbar vertebrae from about the seventh to the third. There was a slight compensatory curve above.

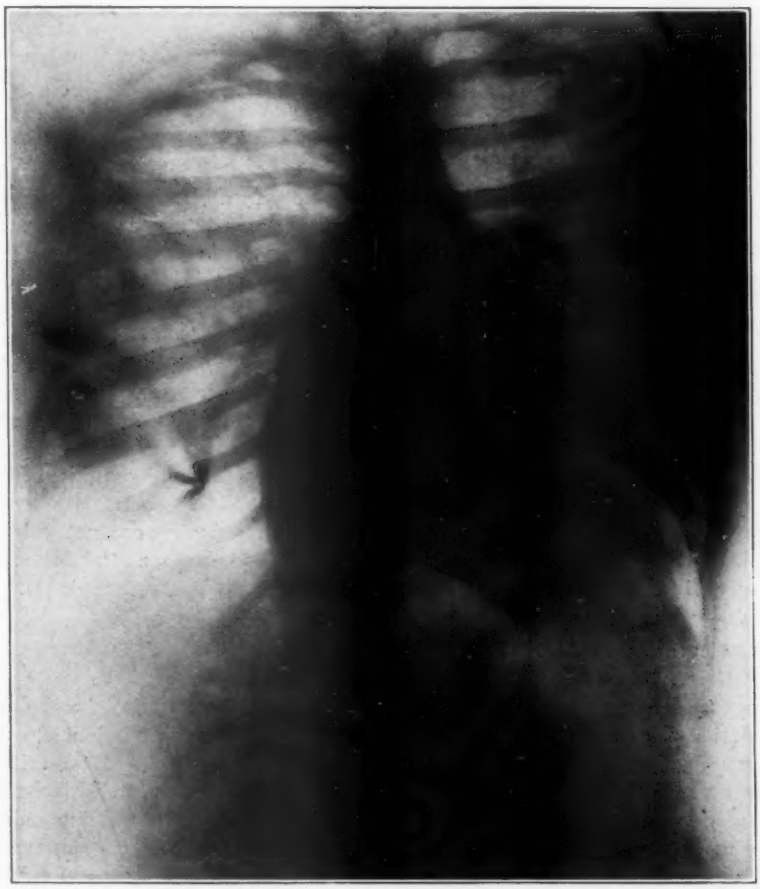

Fig. 14 (Case 2).—Before operation.

November 1 (Dr. Kleinberg): The patient was a well built girl, presenting a right dorsolumbar scoliosis with a slight left lumbar compensatory inclination. The dorsal curve extended from the sixth dorsal to about the second lumbar vertebra. The shoulders were about on a level. The spine from the sixth dorsal to the second lumbar vertebra had a forward curve in contradiction of the often seen kyphoscoliosis. There was a backward displacement of the ribs on the right side, with the most prominent part of the deformity opposite to, or on the angle of, the scapula. On the left side, there was a moderate hollow.

The left "hip" was more prominent than the right. There was a moderate degree of rigidity. The anterior view of the chest was prominent on the left. The right side of the chest was flat. The anterior superior spines were on a level.

A roentgenogram made on October 25 revealed a moderate right dorsolumbar curve extending from about the fourth dorsal to the second lumbar vertebra, with the apex of the curve between the ninth and tenth dorsal vertebrae. There was increased separation of the ribs on the right and slight approximation of the ribs on the left side. The ribs on the left side were practically horizontal instead of inclined downward as in a normal person.

Readmission.—November 6: After several days at home, the patient reentered the hospital to have the plaster-of-Paris jacket applied. It was intended to have the patient in suspension, in the erect posture, with the left shoulder elevated and the right pulled backward.

Treatment.—November 7: An attempt was made to apply a Kleinberg jacket, but when the procedure was half finished the patient became hysterical and finally fainted. The plaster was removed and she was returned to the ward to await another attempt (T. A. Willis).

November 11: A corrective plaster jacket was applied by Drs. Kleinberg and Armitage Whitman. The patient had several fainting spells during the process and vomited freely (T. A. Willis).

Second Readmission.—July 16: The patient had worn a plaster-of-Paris jacket since it had been applied in the outpatient department. Her condition had steadily improved under this treatment. She entered the hospital for an operation to maintain correction of the deformity (Dr. Schwartz).

July 17: From the general appearance, the girl was in good condition. There was no discharge from the ears and nose. The pupils reacted to light. The lymph nodes, cervical, axillary, epitrochlear and inguinal, were not palpable. The knee-jerks were equal. The examination of heart, lungs and abdomen was prevented by a jacket extending from shoulders to pelvis (Dr. Schwartz).

Operation.—July 20 (Dr. A. Whitman): An incision was made from the third to the eleventh dorsal vertebra over the spinous processes. There was at least one-half inch (13 mm.) of subcutaneous fat. The tissues over the tips of the spinous processes were incised, and the periosteum split and stripped away from the spinous processes with a periosteal elevator. Interrupted double catgut sutures were then taken about one-half inch (13 mm.) lateral to the midline, between the spinous processes and slightly overlapping each other, with the idea of controlling the hemorrhage that usually follows division of the interspinous ligaments. The tissues were then divided and the periosteum stripped back from the laminae and for a distance of about one-quarter inch (6 mm.) outward on the transverse processes. The fifth, sixth and seventh dorsal vertebrae were found rotated through an arc of about 45 degrees. With a curved chisel, slivers of bone were removed from the transverse processes to make a continuous bridge between the vertebrae after the articular processes had been gouged out with a curet. The spinous processes were then partially fractured at their bases and overlapped, shingle fashion, so that the tip of the upper processes came in contact with the fractured base of the one below. The vertebrae from the third to the eleventh dorsal were thus treated. The operation was difficult because of the thickness of the muscles and the resultant depth at which it was necessary to work. The ligaments were united with interrupted kangaroo sutures, the subcutaneous tissue with continuous plain gut, the skin with plain

gut. The amount of hemorrhage was slight compared to that encountered in previous operations. A posterior plaster shell was applied. The duration of the operation was one and a half hours.

July 22: Following the operation, the patient complained of pain in the upper dorsal region.

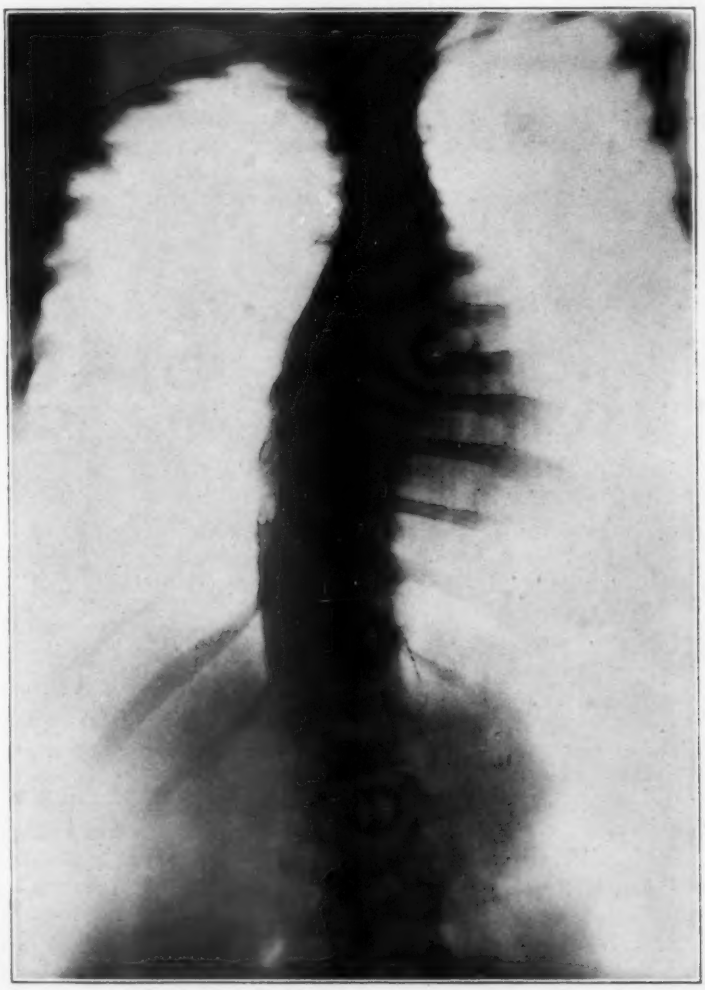

Fig. 15 (Case 2).—After operation.

After-Treatment.—July 29: On the seventh day following operation, an attempt was made to apply a jacket with the patient suspended. She suffered what has been variously diagnosed as hysteria or syncope, with very rapid pulse, cold, clammy skin, and involuntary movements. On this occasion, the attempt had to be given up. The patient's great weight and nervous disposition made it practically impossible to apply a jacket in a horizontal position. Instructions were given that she remain in bed in a posterior shell.

August 12: A jacket was applied, including both shoulders. The patient suffered an hysterical attack.

August 19: The plaster had slipped up, so that the shoulder straps were of no use. The patient was allowed to sit up. Roentgen-ray examination showed the disappearance of intervertebral disks from the third to the eleventh vertebrae and there was slight indistinctness of outline, as of bony proliferation.

September 23: The patient was discharged, improved, wearing a plaster jacket. She was instructed to report for further treatment (V. W. Purdy).

Third Readmission.—October 19: The patient was readmitted to the outpatient department.

October 21: The external appearance of the trunk was normal. A roentgenogram taken October 20 showed an apparent fusion of the spine from the third to the eleventh dorsal vertebra. The intervertebral spaces were still visible, although the mass of the fused area was evidently denser in the middorsal than in the upper and lower extremities.

On examination, no movement could be made out in the dorsal spine. Both forward and lateral bending were very much restricted. This opinion was concurred in by Dr. Kleinberg. A roentgenogram was taken with the patient in the upright position and she was allowed to sit up for gradually increased periods each day.

November 4: The patient was discharged, wearing a plain plaster jacket. She was in good condition (Dr. Nicola).

December 16: The plaster-of-Paris jacket was removed, and the patient was instructed to return in a week. A roentgenogram and photograph were taken.

Outcome.—December 23: The patient had been without the cast for a week. There was no increase in deformity. There was apparently no anteroposterior mobility in the region of operation. The question of lateral mobility was doubtful. The patient was well satisfied with the result. She was instructed to report in two weeks.

March 5, 1921: A roentgenogram taken January 21, when compared with that taken Dec. 16, 1920, showed no change in the deformity. There was a considerable increase in the density of the area of operation. No trace of the intervertebral disks was now seen between the fourth and tenth dorsal vertebrae. The appearance was of a solid bony mass.

July 23: The condition was very satisfactory. The spine appeared stiff and there was no increase in the deformity. The left shoulder was much higher.

July 26: A roentgenogram taken July 23 revealed no increase in the deformity. It offered also interesting testimony as to the fallibility of roentgen-ray evidence, as the roentgenogram taken May 14 appeared to show much greater density in the fused area. Four different observers thought the last plate was the first.

April 25, 1922: The condition was unchanged.

CASE 3.—*History.*—O. P., girl, aged 12 years, entered the hospital July 6, 1920, with a clinical diagnosis of right lateral curvature. She had a history of measles, scarlet fever and whooping cough. Her parents and the other children were alive and well. The chief complaint was spinal deformity of eleven years' duration.

A physician called eleven years previously to treat the patient for fever recognized the spinal deformity. The treatment recommended was fresh air and a milk diet. Two years previously, a physician called to treat the patient for adenoids recommended a plaster corset for the spinal condition. The patient

wore a plaster-of-Paris corset extending from the pelvis to the sixth rib for six months. After removal of the plaster, the child was permitted to go four months without apparatus and then a leather corset extending from pelvis to hip was worn for six months, night and day. The condition had grown worse under this treatment. The corset was discarded because it caused pain. The child walked into the hospital without apparatus. She entered because of steadily increasing discomfort which she referred to the region of the left shoulder (Dr. Schwartz).

Examination.—July 8: The child was in good condition. She presented a most extreme rotary lateral curvature of the spine to the right in the cervical region, to the left in the middorsal, and again to the right in the lower dorsal.

Fig. 16 (Case 3).—Before operation.

The head was carried forward practically to the limit of its capacity. There was extreme projection of both scapulae, and the razor back type of deformity of the ribs on the left side. The curve was rigid. There was a slight secondary deformity of the chest, and flattening of the upper part of the right chest below the clavicle, and prominence of the lower ribs on the left. The distance from the right anterior superior spine to the tip of the right internal malleolus was 29½; the distance from the left anterior superior spine to the tip of the left internal malleolus was 29½.

The child had a peculiar, husky, brassy voice. A laryngeal examination was made to ascertain whether there was pressure on the recurrent laryngeal nerve, and a roentgenogram and photograph were taken. Instructions were given that the patient be kept in bed on a frame with traction on the head and pelvis.

July 27: The patient's deformity had been slightly, if at all, improved by treatment.

August 21: There was no change in the upper dorsal region. Operation was decided on for relief of pain, and if possible to do away with the necessity for wearing a brace with a chin cup.

Operation.—(September 16, Dr. A. Whitman): An incision was made over the spinous processes of the vertebrae from the first to the ninth dorsal vertebra.

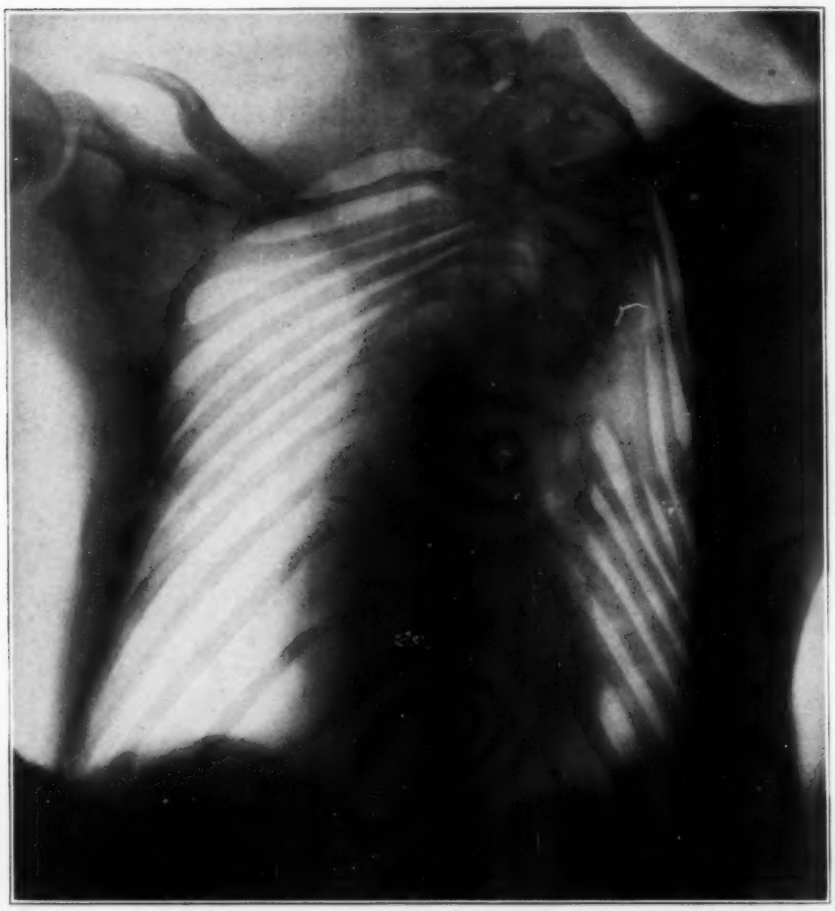

Fig. 17 (Case 3).—After operation.

The tissues over each spinous process were nicked. Double plain gut sutures were then taken 1 inch (2.5 cm.) lateral to the spinous processes, including the tissues between the processes, and tied. This was done on both sides for the purpose of decreasing subsequent hemorrhage. The interspinous ligaments were then divided and the periosteum scraped back from the spinous processes and laminae. This was accomplished with great difficulty at both ends of the wound, owing to the forward bowing of the spine and the great amount of

rotation. The vertebrae were very much distorted, the laminae on the left side being between one-quarter and one-half inch (6 and 12 mm.) in width, and those on the right side scarcely more than one-eighth inch (3 mm.) in width. The laminae were gouged with chisel but the exact Hibbs technic could not be carried out because of the depth at which the laminae lay. The spinous processes were then partially fractured and overlapped. The periosteum and ligaments were united with kangaroo, the subcutaneous tissues with continuous plain gut, and the skin with plain gut. The time of operation was one and a half hours. The patient was then replaced on the frame and traction immediately applied.

September 30: The wound had healed. The patient was able to turn over on the frame without discomfort. She stated that since the operation she had been conscious of less muscular tension drawing her head forward, and was able to move the head and neck with more freedom. A Calot jacket was applied with traction across the shoulders in an anteroposterior direction, with the aim of further reducing the protrusion of the left shoulder. The external appearance had been very much improved. The patient was photographed in the Calot jacket.

October 7: The patient was discharged, wearing a Calot jacket, and in good condition. She was instructed to return December 2 (Dr. Nicola).

October 7: The father said that the child seemed somewhat straighter and taller than before the operation. Her general condition was much improved. Her color and the general tone of the skin were now quite normal.

Readmission.—November 9: The patient had been in a Calot jacket since her discharge two months before. She had been very comfortable. She returned for roentgen-ray examination and further treatment. The jacket was removed.

November 11: There was a very marked improvement in the child's external appearance. Her shoulders were apparently level, the prominence of the left shoulder was reduced about one half. There was apparently stiffness of the spine. A roentgenogram showed that the original curve had been improved almost 50 per cent. There was a cloudiness of the shadows of the vertebral bodies, and obliteration of the intravertebral disks, in the operative region, giving an appearance of fusion. The Calot jacket was applied. Under other circumstances, felt pads would have been introduced in attempting to correct further the prominent scapula, but as the patient lived at a distance and could not afford to remain in the hospital, this was not done. She was discharged, to return in a month for a change of jacket.

Second Readmission.—December 14: The patient again entered the outpatient department for observation.

December 16: The plaster jacket was removed. The improved appearance of the trunk noted at the previous readmission had been maintained. There was apparent stiffness of the operative region. The patient was placed on a frame. Roentgen-ray examination was ordered.

The patient was discharged, wearing a Taylor brace with a chin cup, as her father objected to a Calot jacket. She stated that since the operation she had been entirely relieved of the pain for which it was primarily performed.

Oct. 20, 1921: The patient had not been heard from since she left the hospital. All attempts to get in touch with her failed.

CASE 4.—*History.*—A. B., girl, aged 13½ years, entered the outpatient department, Oct. 1, 1920, with a clinical diagnosis of rotary lateral curvature of the spine. She had had pneumonia at 4 years. The father and mother were living

and well, as were two sisters. One brother died of pneumonia at the age of 6 months. The chief complaint was curvature of the spine, first noticed in the summer of 1919, the child complaining first of tired back. The mother observed a slight curvature, which continued to grow worse. The patient came to the clinic in February, 1920, and a plaster jacket was applied. She had worn the jackets for seven months, with frequent changes of plaster. After seven months, she was given a straight jacket which she still wore. She did not

Fig. 18 (Case 4).—Left, Calot jacket; right, after operation.

complain of any pain at the present time. She entered the hospital for an operation for deformity (Wyant).

Examination.—October 2: The patient had been under treatment in the out-patient department since February 10. She had originally a sharp curve to the right in the dorsal region, extending from the second to the twelfth dorsal vertebra with apex at the eighth dorsal. There was marked wedging of the vertebrae and narrowing of the ribs. The patient wore corrective jackets until August, with slight improvement. The curve was so high and so sharp that further corrective treatment promised, little if any benefit, and a

straight jacket was applied. The patient's family was to return to Italy in the course of the next year, where treatment would almost surely be abandoned. For this reason, they have determined to submit to an operation.

Measurements were: waist, 25 inches (62.5 cm.); chest, below breasts, 28 inches (70 cm.); height, in bare feet, 65¾ inches (164 cm.).

Fig. 19 (Case 4).—Before operation.

October 4: The patient was placed on a frame, with traction of 20 pounds (9 kg.) on the feet and 8 pounds (3.6 kg.) on the head.

October 9: The deformity was slightly improved.

Operation.—October 22: An incision was made over the spinous processes from the second dorsal to the first lumbar vertebra. The tissue over each spinous process was then incised. The periosteum was divided over the tip and stripped downward. This was accompanied by very little bleeding. Over-

lapped sutures were then taken about one-half inch (13 mm.) lateral to the spinous processes, all the way down on either side to prevent hemorrhage during the subsequent procedure. The interspinous ligament was then divided, the tissues and periosteum stripped away from the transverse processes and laminae. The articular processes were curetted. With a V-shaped carving chisel, small slices of bone were removed from the laminae and arranged to interdigitate with the one above as accurately as possible. The spinous process was then half fractured at its base and bent downward so that the tip articulated

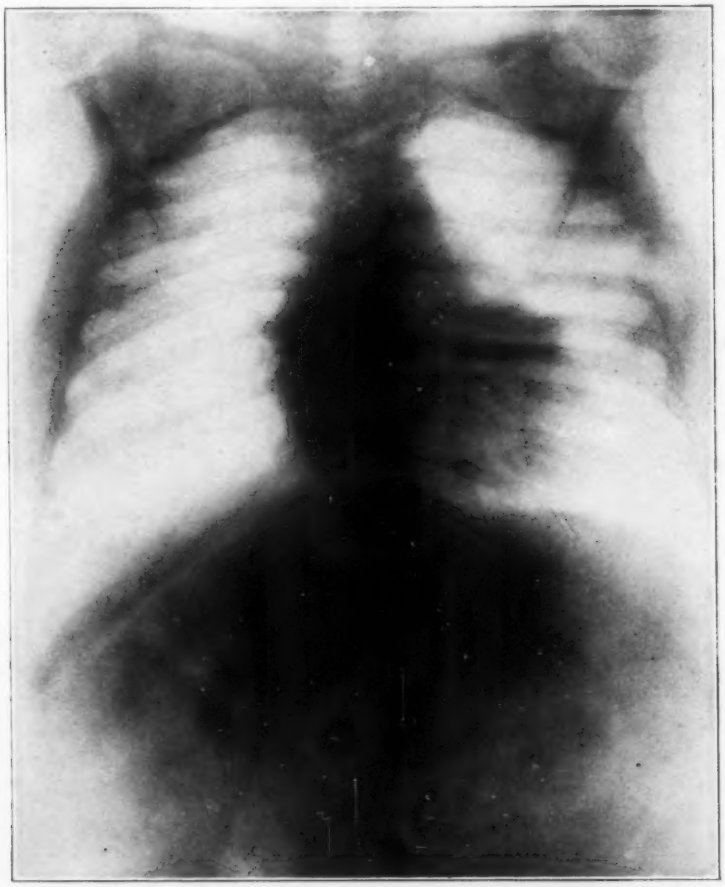

Fig. 20 (Case 4).—After operation.

with the fractured processes of the vertebra below. This procedure was carried out from the second dorsal to the first lumbar vertebra. The rotation of the vertebrae was comparatively slight. The ligatures were practically entirely effective until the bones were incised. The muscular and ligamentous tissues were united with interrupted kangaroo sutures, the superficial tissues with plain gut, and the skin with No. 0 plain gut. Alcohol dressing, sheet wadding and bandage were applied, and the patient was replaced on the stretcher frame. The time required for operation was one hour and three-quarters.

October 28: For five days following the operation, the patient suffered a great deal of pain and discomfort, particularly in the back, and pain on attempts to raise the arms. Following free action of castor oil (October 27), she felt much better and requested the immediate application of the plaster jacket.

November 8: The patient was brought to the plaster room and the dressing was removed. The wound had united by first intention, but there was a small area of necrosis of the skin in the lower portion, apparently from pressure. This was dressed and the patient turned on her face for twelve hours out of twenty-four, the traction in the meantime being kept up.

November 9: The area above mentioned was much decreased in size. A Calot jacket was applied with a window cut out to allow for dressing the wound. A roentgenogram taken after the application of the plaster revealed little if any change either in regard to improvement of the curve or of new bone formation.

November 15: The patient was discharged, in good condition, to return at stated intervals for observation. She was wearing a Calot jacket.

Readmission.—Feb. 8, 1921: The patient had been reporting for observation. She had had no pain or discomfort. She returned to have the jacket removed. While in the hospital, the patient developed influenzal pneumonia.

March 1: The mother insisted on removing the child from the hospital. She was discharged, leaving the hospital against my advice and the advice of others, with a temperature of 103 F.

Outcome.—April 2: The patient had been at home ill with pneumonia. Her general condition was very poor. Forward bending of the spine seemed to be almost entirely restricted, as was shown in tracing. There was, however, undoubtedly some motion of the lower portion of the area of operation. The patient and family expressed themselves as much pleased, and were quite satisfied with the result so far. The patient was instructed to return for observation.

August 18: With her clothes on, the patient showed no deformity whatever. With the shoulders back, the back appeared flat, although there was considerable protuberance of the ribs on forward bending. The patient was completely satisfied with her appearance. She had been without support since October.

May 1, 1922: The patient's condition continued satisfactory.

CASE 5.—*History.*—M. L. girl, aged 15 years, entered the outpatient department, Jan. 14, 1920, with a clinical diagnosis of rotary lateral curvature of the spine, of about one year's duration. She had had the diseases of childhood. The family history was negative. The patient had always been well. About one year previously the parents observed that the right scapula was more prominent than the left. She was taken to Dr. Lessea, who advised a visit to the Hospital for Ruptured and Crippled. The patient was brought to the outpatient department, where she was given a jacket, which she had had changed every two months. She had never had any pain or inconvenience from the jacket. She entered the hospital for correction of the deformity and operation. When examined, April 17, 1920, the patient was in good condition, though of rather pale, pasty, complexion. She stood in the usual slouchy attitude, chest flat, and head forward. She presented a rotary lateral curvature of the spine to the right in the dorsal region, with a slight compensatory curve in the lumbar region. The major curve extended from the third to the eighth dorsal vertebra. There was well marked rotation of the ribs, causing a prominence of the right scapula, visible through the clothing. The curvature was fixed. A corrective jacket was applied.

Comment.—January 20: Since the last two jackets, no further correction of the primary curve had been obtained, all the change taking place above and below and causing exaggerated elevation of the shoulder, which seemed useless and unnecessarily disfiguring. The effect of corrective treatment having thus come to a standstill, operation was determined on, to maintain the correction already gained and to enable the patient sooner to dispense with the apparatus. On removal of the jacket, with the patient lying on her face, there was evident a slight curve to the right in the dorsal region, with a very slight prominence of the ribs. The general aspect of the trunk was symmetrical.

Operation.—Jan. 20, 1921: A 7-inch (17.5 cm.) incision was made in the midline directly over the spinous processes. Typical Hibbs' procedure as described in previous similar operations was carried out from the third to the twelfth dorsal vertebra. The exposure was very satisfactory so that the technic could

Fig. 21 (Case 5).—Left, before operation; right, after operation.

be minutely followed. The vertebrae at the center of the deformity were found rotated through an arc of about 45 degrees. There was very little structural change affecting the width of the laminae. The time of the operation was about one and a half hours. The patient's condition was satisfactory.

After-Treatment.—When the patient returned from the operating room, an electric heater was placed below the frame and the frame and bed were draped with blankets. She had considerable pain, requiring about one-fourth grain (0.0162 gm.) of morphin toward morning.

January 21: The patient was pale, with eyes widely dilated. She complained of severe pain in the back and did not wish to move the arms.

January 22: The general condition was satisfactory.

January 25 (Dr. Kleinberg): The patient was improving and felt much better. The temperature was practically normal. The pain in the back was very slight. The patient could talk barely above a whisper.

January 26 (Dr. Nicola): The throat was congested; the larynx normal except for slight congestion of the cords. There had been recent bleeding from the right nasal passages. Physiologic solution of sodium chlorid, warm, was used to cleanse the nose, three times a day.

February 5: The patient was turned on the face, and the dressings removed. The wound had closed by first intention. Two or three bleeding points caused

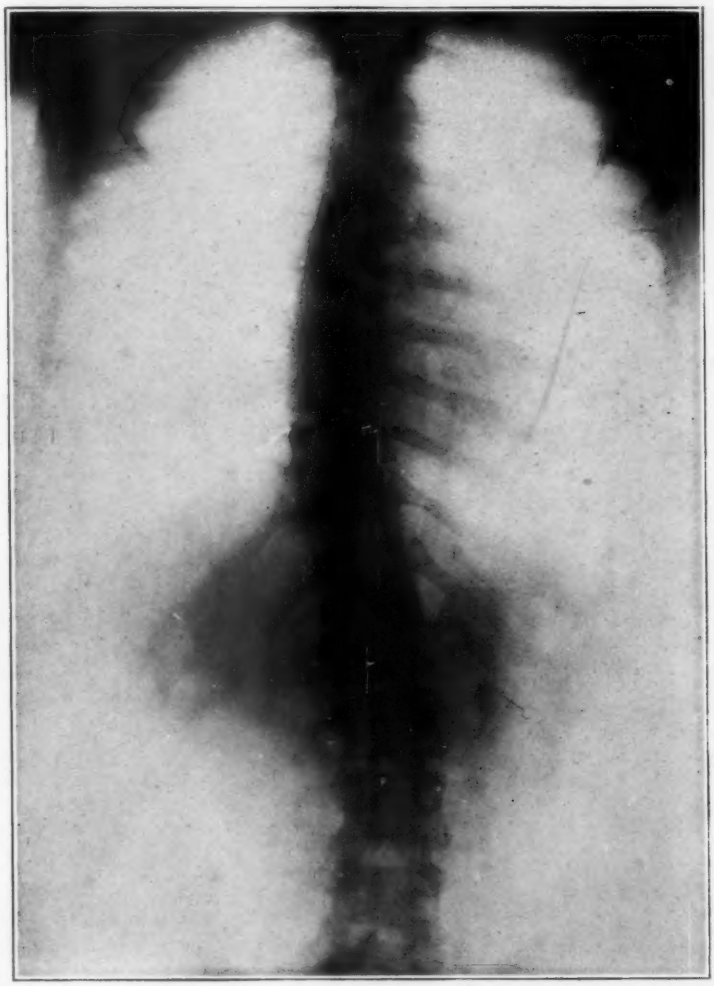

Fig. 22 (Case 5).—Before operation.

removal of the adhesive plaster, but the skin as a whole was very much irritated. The skin was cleansed with benzin, powdered, and dry dressings applied. Weights attached to the pelvic band (February 4) were increased to 20 pounds (9 kg.).

February 27: The patient was comfortable. The temperature had continued normal for four weeks. There was 10 pounds (4.5 kg.) traction on the head and 20 pounds (9 kg.) on the pelvis (Dr. Bost).

March 5: The back was apparently very much flattened since the operation. There was apparently comparatively firm ankylosis of the vertebrae operated on, resisting all movements.

March 19: The spine was apparently fixed throughout the area of operation. The patient was discharged, to return for observation. A photograph was taken.

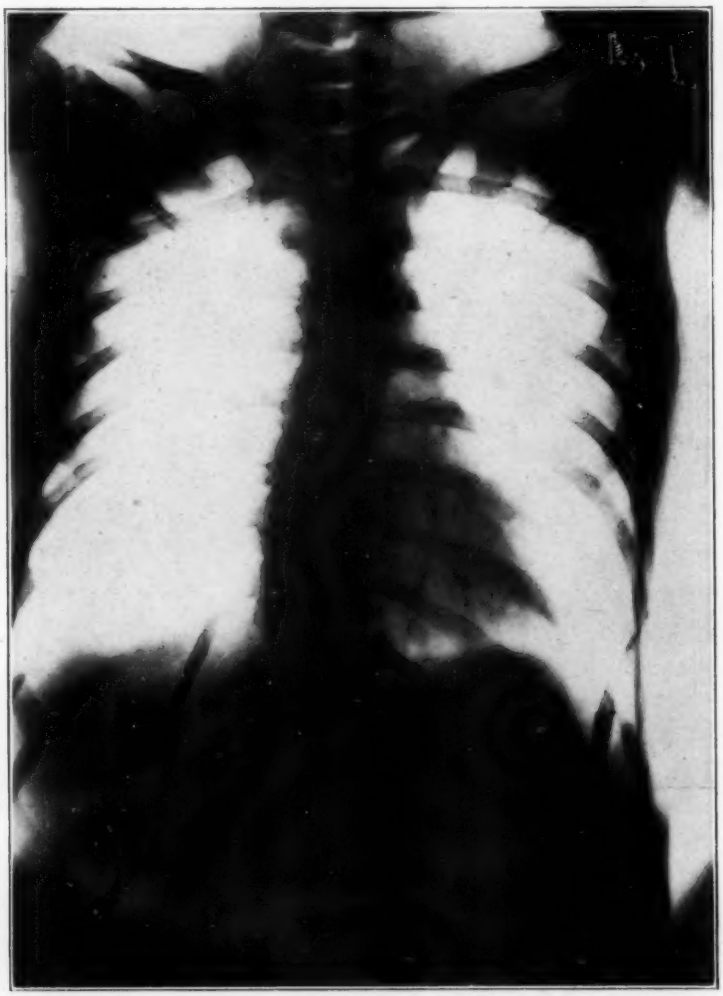

Fig. 23 (Fig. 5).—After operation.

April 16: The patient's habitual posture was very bad. She made no attempt to stand straight. A roentgenogram was made.

May 2: The patient was wearing a corset, which was approved. She was still unable to stand straight. She was instructed to return in two weeks.

June 21: The external appearance was unchanged. The patient was satisfied with her condition, and did not think it was progressing. The roentgenogram

as compared with that taken April 19 revealed a very distinct increase in density in the area of operation. There was no progress of the curve.

July 23: The outcome of the operation itself appeared satisfactory. The patient's posture was as execrable as ever. She was kept on the frame because the irritated condition of the skin made it inadvisable to apply a jacket. It appeared, however, that the spine had stiffened much more rapidly on the frame than in the cases in which the patients were placed in plaster.

May 15, 1922: The patient's general posture was, possibly, slightly improved. There was no change in the spine.

CASE 6.—*History.*—A. P., girl, aged 17 years, entered the outpatient department Jan. 6, 1920, with a clinical diagnosis of rotary lateral curvature of the

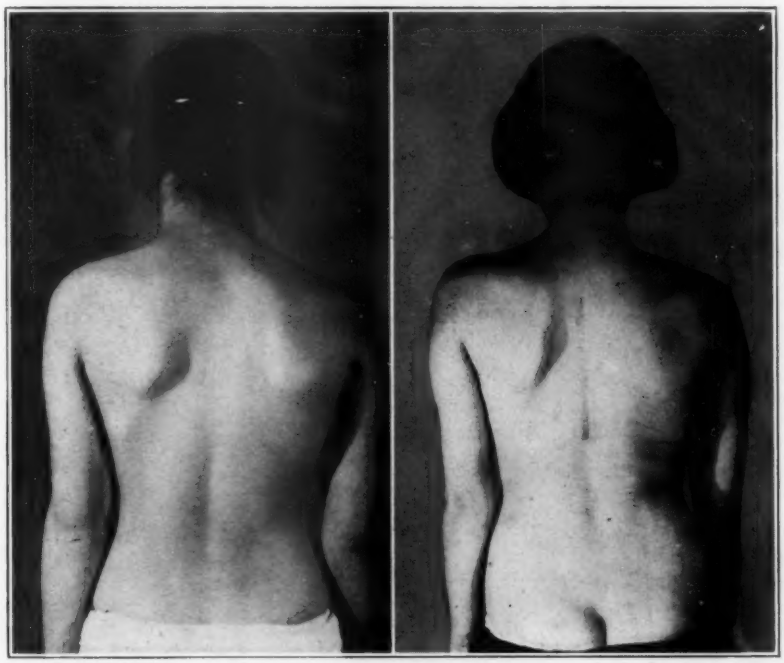

Fig. 24 (Case 6).—Left, before operation; right, after operation.

spine. She had had measles at the age of 3 years. Her father, aged 45, mother 42, two brothers and one sister were living and well. There was no history of tuberculosis, cancer, nephritis or diabetes. The chief complaint was spinal curvature, of two years' duration. The patient complained of a weak back, from which she had suffered for one year. It was gradually becoming worse. She had round shoulders and tired readily.

Examination.—At the present time, the patient had no pain. She had not been ill at the onset. As she stood, the shoulders were approximately level. Prominence of the tip of the scapulae was noticeable on both sides. There was rotary lateral curvature of the spine to the right in the dorsal and slightly to the left in the lumbar region, and considerable rotation of the ribs. The deformity was rigid.

November 9: Plaster jackets had been applied at two-month intervals. A roentgenogram taken September 2 showed a marked overcorrection at the upper and lower extremities of the spine, the original middle curve being almost, but not quite, corrected. As the overcorrection in the upper dorsal region was somewhat undesirable and entirely due to the elevation of the shoulder, the jacket applied October 30 did not include the shoulder. The roentgenogram

Fig. 25 (Case 6).—Before operation.

showed the spine in slightly better position than with the former jacket. Externally the trunk appeared symmetrical although the original dorsal curve was not entirely corrected.

Readmission.—April 24, 1921: The patient reentered the hospital.

Operation.—April 25 (Dr. A. Whitman; assistants, Drs. Bost and Wyant): A. Hibbs operation was performed from the third to the eleventh dorsal vertebra. The usual technic was varied by splitting the spinous processes transversely

and vertically, and spreading the four parts upward and downward, overlapping as much as possible with the fragments of the one below. The attachment of the spinous processes to the vertebral arch was not broken. The tissues were closed with interrupted kangaroo, and No. 1 plain gut for the skin.

There was slight lateral deviation of the spine, but not more than 20 degrees rotation.

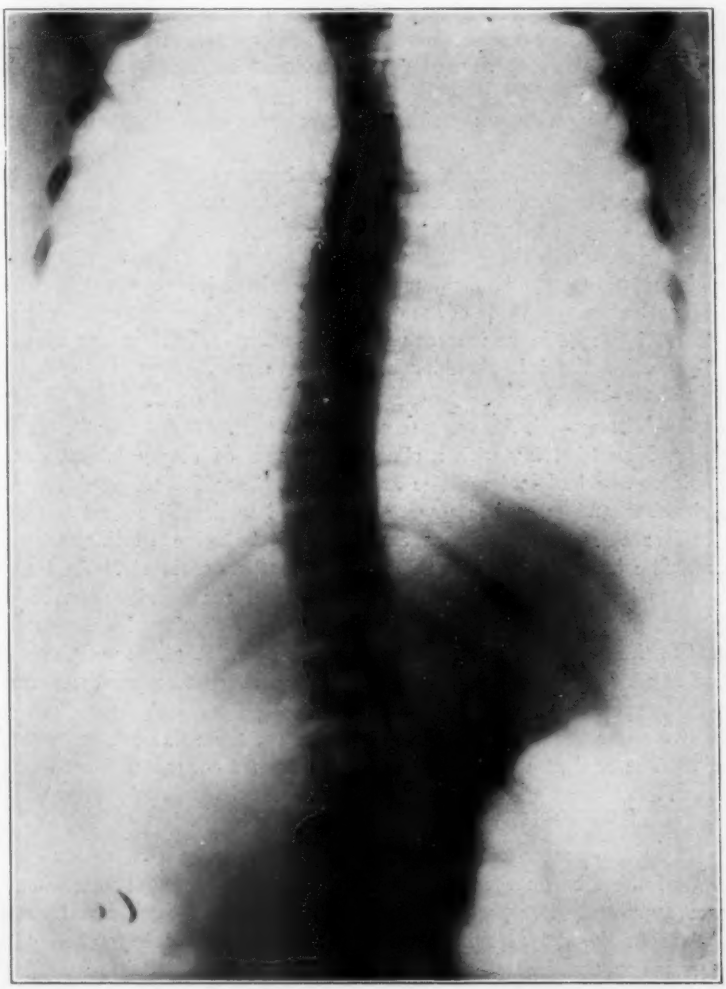

Fig. 26 (Case 6).—After operation.

Outcome.—April 26: The patient had had very little pain following the operation. She now complained of precordial distress.

April 28: The patient was comfortable. Traction was applied.

May 5: The wound was closed by first intention. There was slight redness over the lower end of the scar, and it was also somewhat tender to pressure. The back was clean.

June 12: Beginning June 1, the patient had turned on the face, and voluntarily extended the spine ten times each day, for the purpose of producing exuberant callus in the area of operation. The motion had caused her no pain.

June 18: The area of operation appeared stiff, and a low plaster jacket was applied for the purpose of steadying the lumbar region during the process of muscular recovery.

June 20: The patient was discharged, wearing the plaster jacket; to return for observation (Dr. Wyant).

August 21: The jacket was removed. The patient was cautioned to lie down at frequent intervals, and warned that she would have pain and weakness in the back.

August 28: The patient complained of severe pain in the back and a continual tired feeling.

September 1: The pain in the back had been completely relieved by the application of an ordinary corset.

October 22: The patient had been wearing a corset since the last report. She took no interest in the maintenance of a proper posture and walked about everywhere with the typical fashionable droop. In spite of this, the deformity of the spine had not progressed, and the external appearance was satisfactory.

April 22, 1922: The patient continued to affect the débutante slouch and habitually carried the left shoulder high. There was, however, apparently no change in the spine.

Case 7.—*History.*—E. A., woman, aged 19, a milliner, entered the outpatient department, May 16, 1920, with a clinical diagnosis of rotary lateral curvature of the spine. She had had measles at 10 years. Her father, aged 52, mother, 48, one brother and two sisters were living and well. Two brothers died in infancy. Her chief complaint was curvature of the spine, of thirteen months' duration. She had been well until thirteen months previously. At that time, she began to have pain in the right shoulder and arm, and she noticed that her right shoulder was higher than her left. This continued for one month. She came to the outpatient department, May 23, 1920. A plaster-of-Paris jacket was applied and she had had a new one put on every two months since (Dr. Robert E. Burns).

May 17: After the treatment of the past year, the spine seemed practically corrected. The patient was admitted to the hospital for operation to maintain the correction.

Examination.—The patient was in good condition. Externally, the trunk was somewhat asymmetrical, as is shown in the tracing. There was marked flattening of the ribs on the right side from the pressure of the jacket. The spine was apparently straight. There were very evident flexion and extension taking place in the dorsal spine as was shown in the tracing taken with the patient prone on the frame, and when she lifted herself in the air. The first roentgenogram taken through the plaster, May 27, 1920, showed a slight curve to the right in the dorsal region. The roentgenogram taken through the plaster, Feb. 24, 1921, showed the spine practically straight.

Operation.—May 17, 1921 (Dr. A. Whitman; assistants, Dr. Bost, Dr. Wyant and Dr. Burns): The usual Hibbs operation was performed from the second to the eleventh dorsal vertebra. Considerable rotation of the vertebrae was present, more than would have been supposed from the roentgen-ray or physical examination. The exposure was unusually good, and the procedure very thorough. The usual technic was varied by splitting the spinous processes vertically and

again horizontally, and then spreading the fragments in the four directions. This appeared to give unusually good bony contact. The time of operation was one hour and twenty minutes. The pleura on the left side was penetrated by an artery clamp in the hands of an assistant. The perforation was immediately closed by allowing the muscle to fall over it.

Outcome.—May 22: The chest was examined anteriorly. It was resonant, and there was vesicular breathing. No friction rub was felt or heard. There were no râles (Collens).

May 24: The patient's convalescence had been uneventful, except that she had complained of occasional pain. The dressings were removed. The wound was closed by first intention. There were signs of pressure at the lower extremity of the wound.

Fig. 27 (Case 7).—Left, before operation; right, after operation.

June 24: A roentgen-ray examination of the spine throughout the area of operation revealed an apparent complete fusion, in that the intervertebral spaces were scarcely visible.

June 26: A confirmatory roentgen-ray examination failed to reveal any fusion whatever.

July 13: The spine appeared stiff in the area of operation. A low plaster jacket holding the lumbar region in position was applied. A roentgenogram of the region of operation was taken.

July 15: A roentgenogram showed no change. The patient was discharged, wearing a plaster jacket; to return for observation.

August 9: The patient was comfortable. The jacket was in good condition. There was no alteration in the external aspect of the trunk.

September 27: The patient was now wearing an ordinary corset and suffered occasional weakness and discomfort in the lumbar region, and in the arms. She felt, however, that she was steadily improving. The external appearance of the trunk was symmetrical. There was apparently, complete rigidity of the area of operation.

May 1, 1922: The patient's general and local condition was excellent.

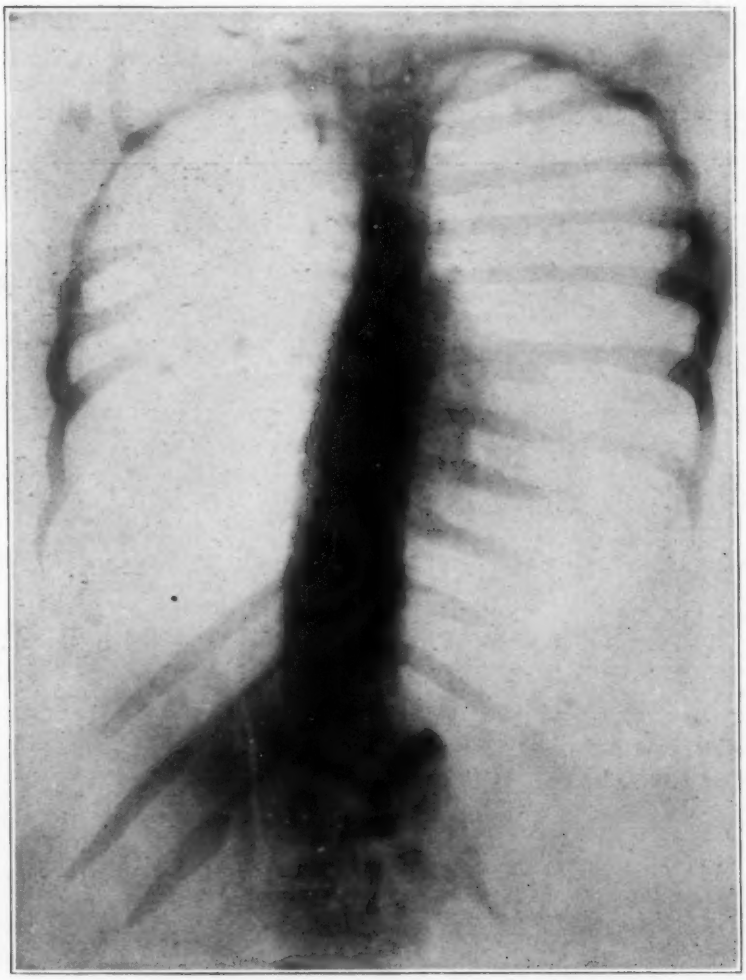

Fig. 28 (Case 7).—After operation.

CASE 8.—*History.*—M. C., girl, aged 16 years, was admitted to the outpatient department with a clinical diagnosis of rotary lateral curvature of the spine. She had had measles and whooping cough at 2 years. Her father, aged 45, mother, 44, one brother and two sisters were living and well. One brother died of pneumonia at 27 months, and one sister, of spinal meningitis at 3 months. The chief complaint was curvature of the spine, of two years'

duration. Two years previously, the patient's mother noticed that she had a spinal curvature. Nothing was done about it for one year. The trouble became worse during the interval, and, April 15, 1920, she presented herself at the hospital for treatment. She was put in a cast. Except for changes every two months, she had worn it continuously since. Every two months, she had had a roentgenogram taken at the time the cast was changed. The condition had improved, but in order to prevent a recurrence, she entered the hospital to have an operation to fix—"stiffen"— the spine. When examined April 13, 1920, the patient was in fair condition. She presented a rotary lateral curvature of the spine to the right in the dorsal region. There was extreme prominence of the

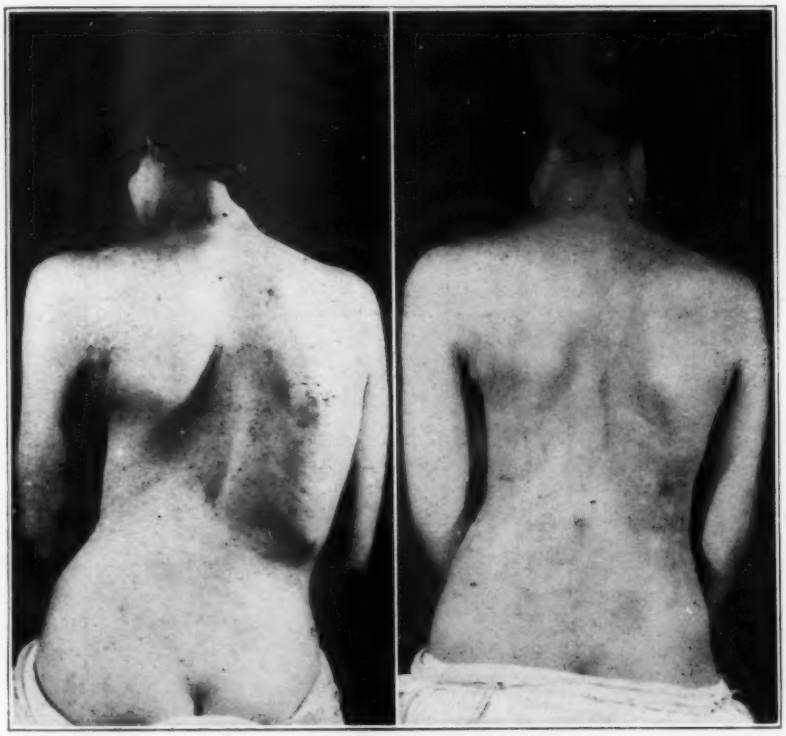

Fig. 29 (Case 8).—Left, before operation; right, after operation.

ribs on the right side, amounting to razor back deformity, with corresponding concavity of the ribs on the left. The spine apparently was completely rigid. A roentgen-ray examination was made and photograph taken.

April 2, 1921: No improvement was made between the application of the last and next to the last jacket. The patient was therefore admitted for treatment on a frame with traction, as a preliminary to operation. The external appearance of the trunk was one of almost complete symmetry. There was still slight prominence of the lower ribs on the right side. There was a slight curvature palpable to the right in the dorsal region.

Operation.—April 6 (Dr. A. Whitman): The usual Hibbs operation was performed, from the second to the twelfth dorsal vertebra. The bleeding was

entirely controlled by packing. No ligatures were tied. There was very slight lateral deviation of the spine, but considerable rotation, to about 25 degrees. The experiment was tried of correcting the rotation by pressure on the spinous processes, which proved quite impossible. One could barely move the vertebra, which immediately returned to its original position. The ligamentum nuchae

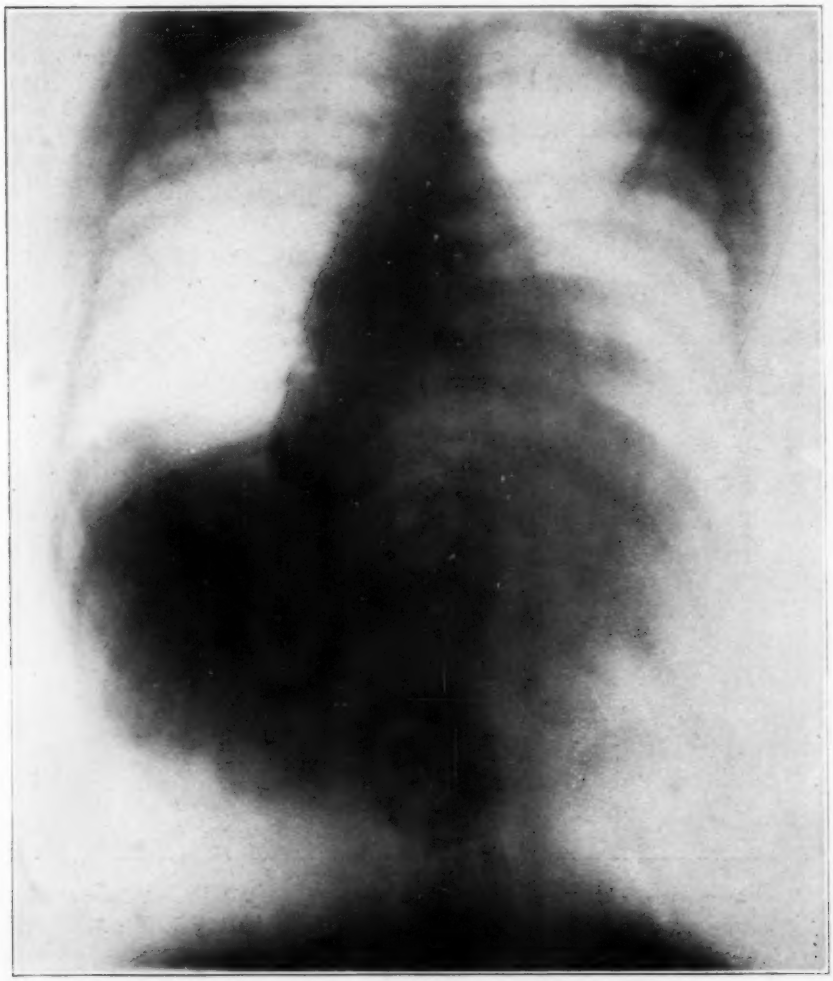

Fig. 30 (Case 8).—Before operation.

was sutured with kangaroo, the subcutaneous tissues sutured with plain gut, the skin with 0 plain gut.

The patient had a copious bowel movement during the operation which was noted, in case infection might develop.

After-Treatment.—April 19: On account of the irregular temperature and the blood count, the patient was dressed on the eighth day. The wound was completely healed, and there was no sign of superficial infection. The con-

valescence, except for the variations in temperature, had been extraordinarily smooth. The patient had not complained of pain since the first twenty-four hours. All dressings were removed. Traction was reapplied on the fourth day. The patient now had 20 pounds (9 kg.) traction on the waist and 5 pounds (2.3 kg.) on the head. The appearance of the back was satisfactory.

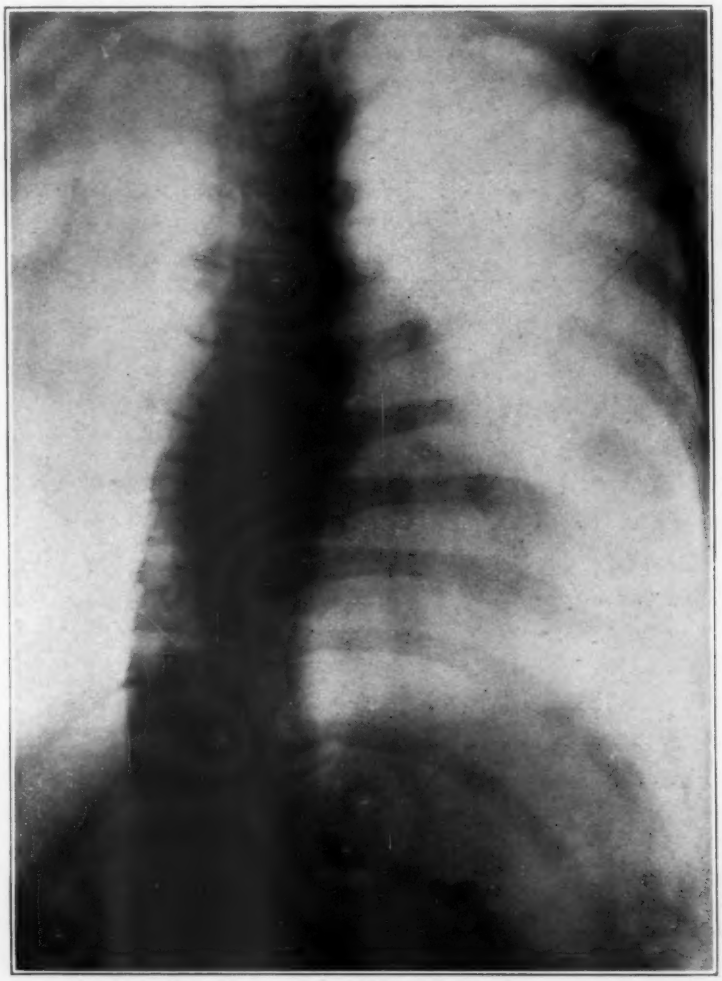

Fig. 31 (Case 8).—After operation.

April 28: The patient was turned on the face and there seemed to be some lateral fixation.

May 17: The patient was removed from the frame and was taken to the plaster room to have a corset applied. She was to return for another week on the frame, but she preferred a jacket to a corset. On this account, she was allowed to sit up (May 19).

Outcome.—(Dr. Bost): May 20, she was discharged, improved.

July 21: The spine was apparently stiff. The patient was satisfied that the deformity had not progressed. She wished to wear the plaster through the summer. A roentgenogram was taken.

October 20: The patient had worn a plaster corset at her own request throughout the summer. It was now removed and an ordinary whalebone corset substituted. The patient was instructed to return to the gymnasium at regular intervals for exercises. There was great atrophy of the lumbar muscles, but apparently no increase in deformity.

December 28: There was still considerable atrophy of the lumbar muscles. Exercises were advisable, but apparently impossible. There had been no change in the deformity of the spine.

May 18, 1922: The patient had been taking exercises. The general condition and appearance were excellent.

Case 9.—*History.*—L. S., boy, aged 12 years, entered the outpatient department, Dec. 11, 1919, with a clinical diagnosis of lateral curvature of the spine.

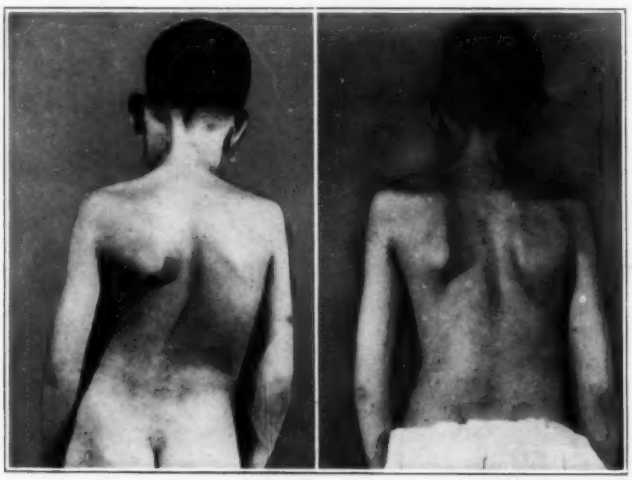

Fig. 32 (Case 9).—Left, before operation; right, after operation.

He had had whooping cough when 2 months old, measles at 4 years, and typhoid fever at 6. He was very sick with typhoid fever for three months. Following this, he had hemorrhages, which subsided after the removal of his tonsils. The family history was negative. The chief complaint was curvature of the spine, of 1 year and 8 months' duration. Two years previously (October, 1917), the patient had fallen from a horse, landing on the cement floor of a barn, breaking the left forearm. It was following this that the curvature of the spine was noticed. Aside from massage and manipulation, nothing had been done to correct this condition (V. W. Purdy).

Examination.—December 13 (Dr. Whitman): The boy was in good condition. He stood with the trunk displaced toward the right side, and the left pelvis very prominent. There was marked fixed general rotary, lateral curvature, involving the entire dorsal region up to about the sixth vertebra. There was marked deformity of the ribs and a fair degree of flexibility.

December 13: A corrective jacket was applied.

December 16 (Dr. Kleinberg): A roentgenogram taken Dec. 13, 1919, following the application of a corrective jacket, showed very marked reduction of the dorsal curve.

Readmission.—March 16, 1920: The patient had been ill since leaving the hospital, for about one week, five weeks before. The physician said that he had purpura hemorrhagica. Nothing had been done for his orthopedic condition

Fig. 33 (Case 9).—Before operation.

since his discharge. The old plaster was now removed and replaced with a new one (B. L. Schoolfield).

March 17: The patient was discharged wearing the plaster jacket. (B. W. Moffat).

Comment.—April 2: The last jacket, applied four months ago, did not include the right shoulder, as there appeared to be too much exaggeration of the curve

above the original deformity. A corrective jacket was applied elevating the left shoulder and depressing the right. On removal of the last jacket, there was no apparent curvature of the spine. There was very slight prominence of the ribs on the right side, and a mild curvature to the right extending from the fourth to the twelfth dorsal vertebra. The external appearance of the trunk was excellent.

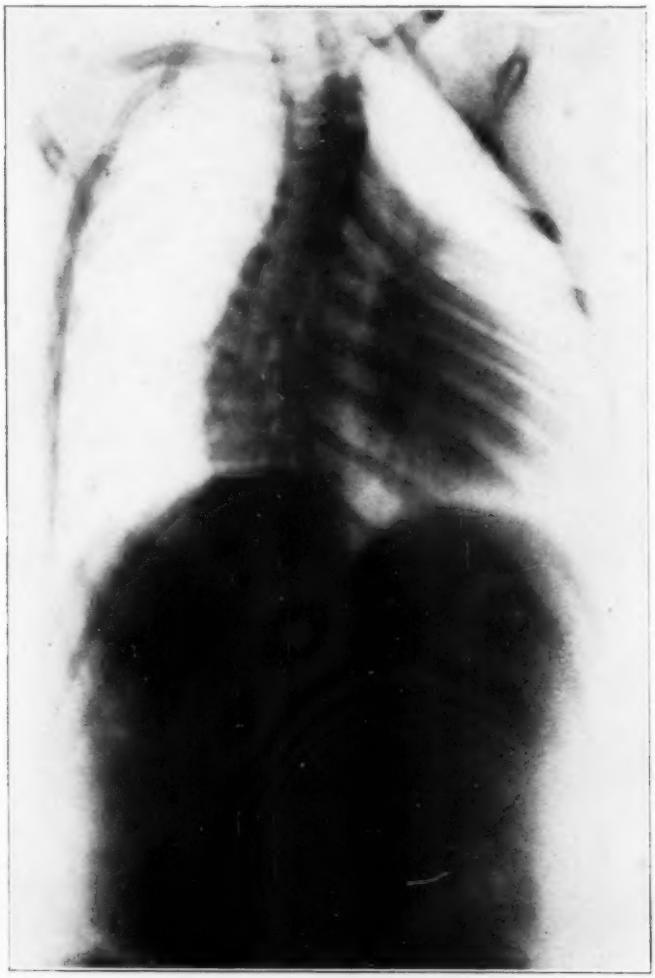

Fig. 34 (Case 9).—After operation.

Second Readmission.—July 12 (Dr. Whitman): Since the last report, the boy had been under continuous treatment by jackets. He now returned for operation. The extreme deformity of the spine was almost corrected, as shown by the tracings.

Operation.—July 20, 1921 (Dr. A. Whitman; assistant, Dr. Wyant): A fusion operation extending from the third dorsal through the first lumbar vertebra was

performed. The exposure was unusually good, and for the first time I felt certain that I had destroyed the articulations between the vertebrae. The spinous processes were split in four parts vertically and horizontally; two were turned up, and two down, so that the interdigitation was very satisfactory. The ligaments were sutured with kangaroo and chromic gut. The skin was closed with catgut. An alcohol dressing was applied. The time of operation was one hour.

After-Treatment and Outcome.—July 26: The dressing was changed; the wound was clean; a dry dressing was applied (R. E. Burns).

July 30 (Dr. Whitman): After the operation, the patient complained of pain in the left shoulder. Many of these patients complained of pain in the shoulder, although the line of incision was not opposite the shoulder.

August 4: The patient was very comfortable, except for occasional pains in the left shoulder which were not very severe (Dr. Sneed).

The wound was dressed. It was entirely healed (R. E. Burns).

September 3: The spine was stiffening. The external deformity of the ribs was somewhat improved.

September 15: The wound was entirely healed. The patient was removed from the frame and a plaster jacket applied, shoulders not included (Dr. Wyant).

The patient was discharged wearing a low plaster jacket to support the lumbar region.

November 20: The plaster corset was removed and a canvas reinforced corset reapplied. There were atrophy of the lumbar muscles and some stiffness in the lumbar region. Massage and exercises were prescribed.

December 20: The patient reported by letter that his improvement continued.

April 22, 1922: There was no progress of the deformity. The general condition was excellent.

CASE 10.—*History.*—C. M., girl, aged 16 years, entered the outpatient department July 22, 1921, with a clinical diagnosis of rotary lateral curvature of the spine. Her general health was excellent. She had had the usual diseases of childhood. Her mother died of pneumonia at the age of 48. The history of the father was unknown. There was no history of cancer, tuberculosis or heart disease. The chief complaint was curvature of the spine, of two and a half years' duration. Nothing unusual was noted about the child until she was 12½ years of age, when an aunt noticed that the right shoulder drooped. It was thought that the carrying of school books caused it. The child was brought to the hospital and a plaster cast was applied. She had worn it constantly for two years, and now came in for operation (Dr. Wagner).

Physical Examination.—The child was in fair condition; very pale, flat chested and evidently considerably under weight. She presented a well marked rotary, lateral curvature of the spine to the right in the dorsal region, with a slight compensatory curve to the left in the lumbar region. The right shoulder was high, the left hip prominent. There was considerable rotation of the ribs, and prominence of the scapulae. A roentgenogram and photograph were taken, and corrective jackets prescribed.

Since July, 1919, the patient had been under treatment in the outpatient department, corrective jackets being applied at intervals of two months. She had, apparently, now reached the maximum correction and was sent to the hospital for operation.

Operation.—July 26, 1921 (Dr. A. Whitman; assistant, Dr. Wyant): The fusion operation was performed from the third dorsal to the twelfth dorsal vertebra. There was very slight rotation of the spine and no lateral deviation. The

spinous processes were split horizontally and vertically, and then pried upward and downward, giving a very satisfactory interdigitation. It was also thought that the intervertebral articulations were effectually curetted. The ligaments were sutured with chromic gut, the subcutaneous tissues with plain gut, the skin with horse-hair. The time of operation was one and one-half hours.

Outcome.—July 28: There was bleeding through the dressing the night following the operation. The general condition was excellent. The patient suffered very little pain.

August 2: The wound was clean. The stitches were removed and dry dressing applied.

Fig. 35 (Case 10).—After operation.

August 23: A roentgenogram showed for the first time, in the series of cases, apparent destruction of the articular processes.

September 3: The external appearance of the patient's back was satisfactory and there was evident beginning stiffness in the operative area.

September 24: The patient was removed from the frame and a plaster jacket applied.

September 26: The patient was discharged, wearing a plaster-of-Paris jacket, to return for observation in one week (Dr. Wyant).

December 20: The plaster corset was removed and an ordinary reinforced corset substituted. The patient was instructed to take exercises for the lumbar muscles and gradually to discard all apparatus.

April 22, 1922: The condition continued to be satisfactory.

CASE 11.—*History.*—B. K., schoolgirl, aged 12 years, entered the outpatient department, Aug. 5, 1920, with a clinical diagnosis of rotary lateral curvature of the spine. Her general health was extremely good. She had had the usual diseases of childhood; no pneumonia nor typhoid. Her mother, aged 59, and father, 50, were alive and well. There was no history of cancer, tuberculosis,

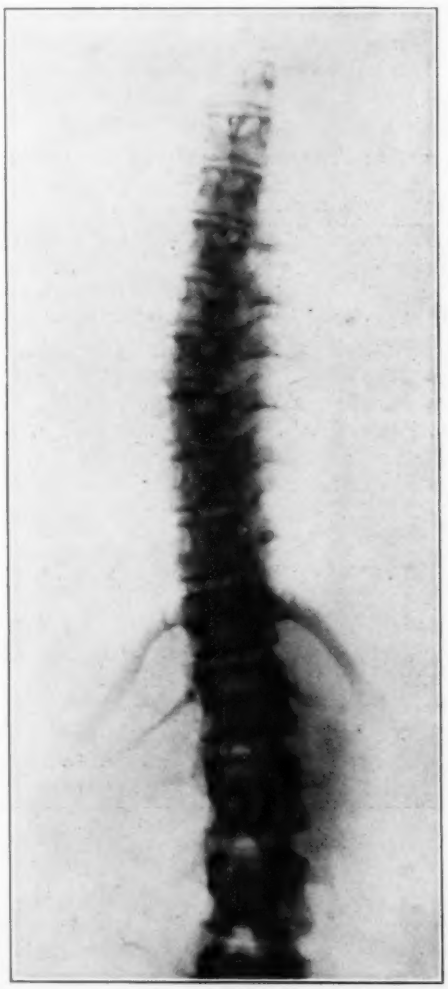

Fig. 36 (Case 10).—After operation.

or heart disease. The chief complaint was curvature of the spine, of one year's duration. When the child was 11 years old, the mother noticed that the right shoulder and the right side of the back were more prominent than the left. She was sent to the outpatient department and had been treated continuously with plaster jackets. She complained of no pain and came in for operation (Dr. Wagner).

Physical Examination.—The child was in good condition, and stood very erect. She presented a lateral curvature of the spine to the right, a long, single curve extending throughout practically the entire length. The spine was flexible, but the curve could not be entirely corrected. The left hip was exceedingly prominent. There was comparatively slight rotation. The case seemed especially favorable for corrective treatment. A roentgenogram and photograph were taken.

August 3: The corrective jackets had been applied at two-month intervals. According to the roentgenogram, the curvature of the spine was now completely corrected. This correction, however, had been obtained at the cost of considerable flattening of the right chest. The patient entered the hospital for operation to assure the maintenance of the correction.

Treatment.—August 6: The jacket was retained until the frame could be made (Dr. Wyant).

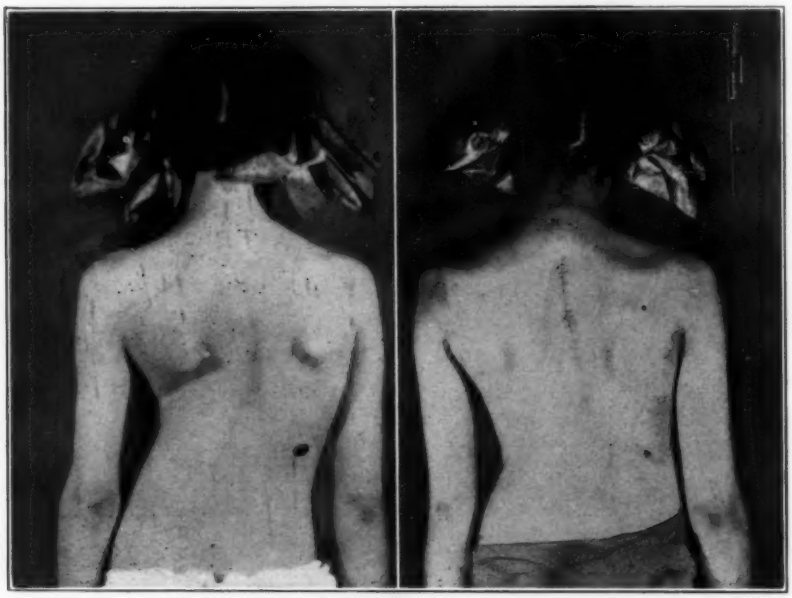

Fig. 37 (Case 11).—Left, before operation; right, after operation.

August 12: The patient was placed on the frame with 5 pounds (2.3 kg.) traction on the head and 10 pounds (4.6 kg.) on each leg, as a preliminary to operation.

Operation.—Aug. 16, 1921: The operation extended from the third to the twelfth dorsal vertebra. There was no lateral deformity but there was about 45 degrees of rotation in the middorsal region, with corresponding distortion of the laminae and transverse processes. The usual technic was carried out with thoroughness, great attention being paid to the attempt at destruction of the articular processes. The spinous processes were split horizontally and vertically, and turned upward and downward, interdigitating in a very satisfactory manner. The ligaments were closed with chromic gut, the subcutaneous tissue with plain gut, and the skin with horse-hair. The time of operation was one hour and ten minutes.

August 19: The patient recovered from the operation very satisfactorily. She was now on a convex frame continuously but no traction was applied as yet. She complained of very little pain.

August 21: The wound was in excellent condition. There was no swelling or redness, and no tender areas. There was a slight rise in temperature, but no discomfort (Dr. L. Wagner).

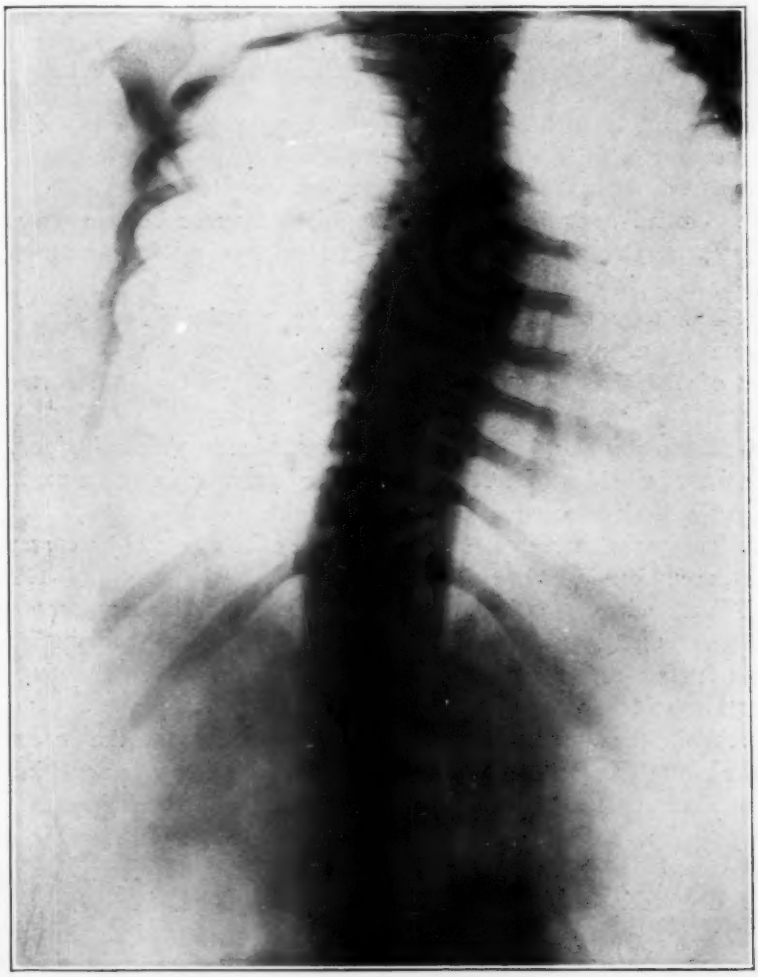

Fig. 38 (Case 11).—After operation.

August 25: The dressing was changed and the stitches were removed from both wounds, which had healed by first intention (R. E. Burns).

September 3: On the patient's eighth day she was discovered turned on her face, propped on her elbow, conversing with her sister. This fact is noted as indicative of lack of postoperative pain.

September 9: The weights on each side of the pelvis were increased to 10 pounds (4.6 kg.). The weight on the head had also been increased to 10 pounds.

The patient complained of no discomfort. Right angled splints were applied to each foot (Dr. Wagner).

October 18: The patient was removed from the convex frame and a low straight plaster jacket was applied. She complained of no discomfort (Dr. Wagner).

December 27: The plaster corset was removed and an ordinary corset substituted. The patient was instructed to have massage and exercises for the lumbar muscles. Her general appearance was excellent.

May 1, 1922: The patient's condition has continued to be satisfactory.

SUMMARY

1. Given a structural scoliosis of unknown origin in the case of an adolescent who applies for treatment because of progressive deformity, the prognosis as to the arrest of deformity is uncertain.

2. A certain number of such conditions may be held in check by apparatus and exercises, provided the patients at all times take a personal interest in their posture.

3. The only means of improving the actual deformity and the external appearance of the trunk is by apparatus embodying at least some of the principles outlined in the description of the corrective jacket.

4. The maximum degree of improvement having been obtained, the spine must be held corrected for a period of years while accommodative changes in the vertebrae take place.

5. This maintenance of correction can be effected only by a corrective jacket, recumbency, or operation.

6. As a climax to the corrective treatment, and as postoperative fixation, recumbency on the convex stretcher frame has proved effective in still further reducing the deformity of the ribs, and in allowing full opportunity for chest expansion.

7. While the amount of actual anatomic correction of the deformity of the vertebrae is exceedingly doubtful, the improvement in the patients' external appearance seems to have been maintained by the operation. It has also greatly abbreviated the period of their convalescence.

8. The older the patient, the more rapid the ankylosis.

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THE OPERATIVE TREATMENT OF SCOLIOSIS*

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NEW YORK

The problem of the complete correction or cure of structural scoliosis is still unsolved. Thus far treatment has been directed toward, and necessarily limited to, reducing the curvature, improving the appearance of the back and maintaining that improvement. There are various methods of treatment whereby improvement may be obtained in a large percentage of cases, but there is no known method which assures permanent results. To make sure that the correction will be lasting, we have been compelled to prolong the treatment over a period of from five to ten years. If a patient, after having undergone corrective treatment for several years, has retained the improvement and has shown no signs of relapse during an additional period of two or three years, we feel warranted in believing that the deformity will not increase. We can, however, at no time feel positive about this, for we all see cases become worse when treatment is interrupted, and sometimes even while corrective treatment is in progress. The deformity may even remain stationary for a number of years and then become more severe. I have seen scoliotic deformity increase during adult life. While, therefore, it is true that some cases remain mild and stationary, with or without treatment, the fact remains that in many patients the deformity does become severe and that in any given instance we are unable to prognosticate the course or state with any assurance that the deformity has reached its greatest development.

Some more certain method must, therefore, be found whereby a given spinal curvature can be fixed, so to speak, so that it will not increase. Such a method might then be applied in the earliest stages of the deformity and the many very severe curvatures of the paralytic, rachitic and razor-back variety might be prevented.

Dr. Hibbs,[1] encouraged by the results of his fusion operation in Pott's disease, reasoned that this operation ought to give satisfactory results in scoliosis. He has operated, we are told, in many cases, and believes that fusion of a part of the spine in scoliosis will prevent further increase of deformity. Dr. A. Mackenzie Forbes[2] also believes that fusion of the vertebrae will arrest the course of the deformity.

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* Read before the Orthopedic Section of the New York Academy of Medicine, April 21, 1922.

1. Hibbs, R. A.: Treatment of Deformities of the Spine Caused by Poliomyelitis, J. A. M. A. **69**:787 (Sept.) 1917.

2. Forbes, A. M.: J. Orthop. Surg. **2**:357 (June) 1920.

He uses a somewhat different technic from that employed by Hibbs. The principle, however, is the same. Both Hibbs and Forbes aim to obtain osseous fusion of the posterior arches of a number of vertebrae, usually from eight to twelve, in the belief that a solid spinal column will have less tendency to rotary lateral deformity than a segmented one. Whether this is true, time and experience alone will teach us; but the hypothesis is reasonable and this treatment deserves an extensive trial.

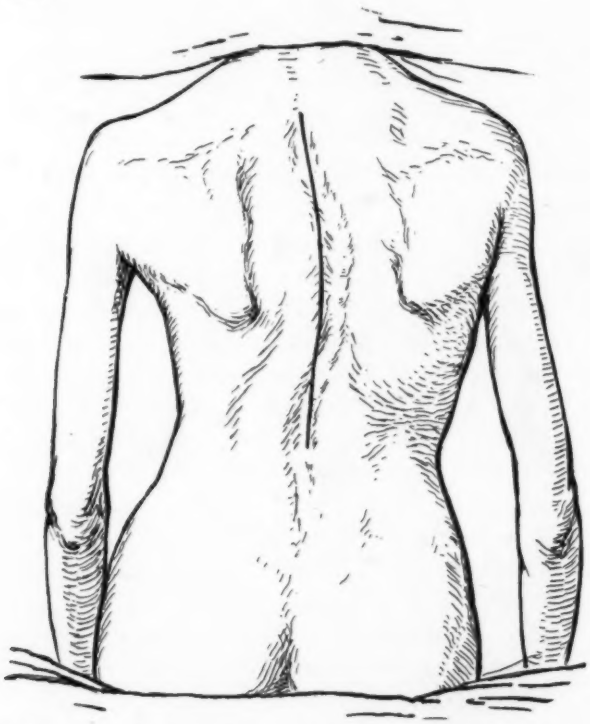

Fig. 1.—Right dorsal scoliosis, showing line of incision extending from second dorsal vertebra to dorsolumbar junction.

Believing that the operative treatment has much to recommend it, and that it may actually afford an opportunity of arresting the progress of scoliotic deformity, I adopted it about two years ago. In my earliest cases I used the Hibbs fusion operation.[3] I found, however, that I did not always obtain complete bony ankylosis. This appeared to be due to the fact that I had operated in very severe cases in which, on account of the extreme deformity of the vertebrae and ribs, it was practically impossible to carry out all of the steps of the Hibbs fusion

3. Humphries, R. E.: The Operative Treatment of Scoliosis, Tr. Sec. Orthop. Surg., A. M. A., 1921, p. 58.

technic. I, therefore, decided to supplement the Hibbs fusion by the use of a beef bone graft. I chose a heterogenous graft for two reasons: First, its use would not prolong the operation as would the removal of a graft from the patient's tibia; second, it could be prepared of the desired length and thickness and with the necessary curve, which may not be possible with the autogenous graft.

At the Hospital for Ruptured and Crippled, fusion of the spine in scoliosis forms but a part of a system of treatment which not only is believed to be satisfactory, but which also is likely to displace the older jacket and brace methods. This treatment may be divided into the preoperative, operative and postoperative phases.

PREOPERATIVE TREATMENT

From my experience [4] in the last few years with the use of suspension in the application of corrective jackets, I know that improvement results from fixation of the trunk, with the spine in extension or hyperextension. The projection of the ribs is reduced; the deformity becomes less conspicuous; the appearance of the back is improved, and there is an opportunity for proper expansion of the chest. It was, therefore, suggested by Dr. Royal Whitman [5] that the patient be placed on a frame for a short time so that some improvement might take place before fusion of the spine is undertaken. This procedure has proved unusually profitable to the patient, and now forms an exceedingly important part of our treatment. It has gradually been modified and extended so that the developed routine is as follows: A convex frame is placed on the bed, extending between, and resting on, the head and foot pieces. The highest part of the arch is at about the mid-dorsal region, with two sections of the curve forming an angle of about 160 degrees. The patient lies on the frame continuously. Traction is applied to the head by means of a Sayre halter, and to the trunk by a pelvic belt with weights suspended from cords running over pulleys at the foot of the bed. At first the patient lies on the frame for several days without any pull to permit her to become accustomed to the position. It is rather surprising how rapidly this occurs, so that eating, sleeping and resting are very comfortable. After a few days a pull of a few pounds is applied, and as the patient becomes accustomed to it, the weights are increased. The weight on the head varies between 5 and 10 pounds (2.3 and 4.5 kg.), and that on each side of the pelvis is somewhat greater. When there is much anteroposterior or lateral deformity, a Balkan frame is set up, and forward or lateral traction is used in addition. All traction is removed during

4. Kleinberg, Samuel: Surg., Gynec. & Obst. **32**:364 (April) 1921.
5. Whitman, Royal: J. Orthop. Surg. **3**:330 (July) 1921.

meals, for the morning bath, and for daily massage. It was found that in some of the cases, the children were very weak when taken off the frames, and for many days locomotion was unsteady and difficult and that the legs and feet were swollen. This has been prevented in our recent cases by daily massage of the back and legs. In this way, the

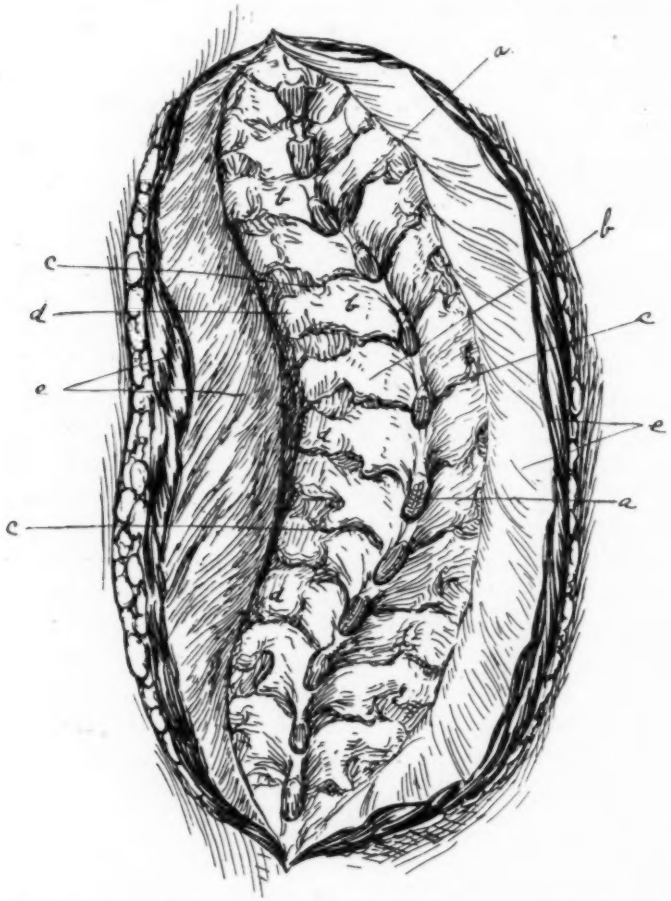

Fig. 2.—Exposure of posterior arches from first to twelfth dorsal vertebra. The Hibbs fusion operation is carried out from the third to the tenth dorsal vertebra, inclusive: *a*, spinous processes; *b*, laminae; *c*, articular processes; *d*, transverse processes, and *e*, periosteum and muscles.

circulatory and muscular tone has been retained and no further difficulty has been experienced in walking. When the maximum degree of correction has been obtained, the patient is ready for the operation.

It came as a pleasant surprise to find that within a short time a very marked degree of improvement was seen. Apparently, relaxation of the tissues occurs during recumbency and the traction and hyper-

extended posture reduce the curvature. Within from four to eight weeks, a degree of improvement is seen which would not be attained in less than six, or more, months by the method of corrective plaster-of-Paris jackets. I am convinced that the maximum degree of improvement in a given case can be obtained in from one to two months by

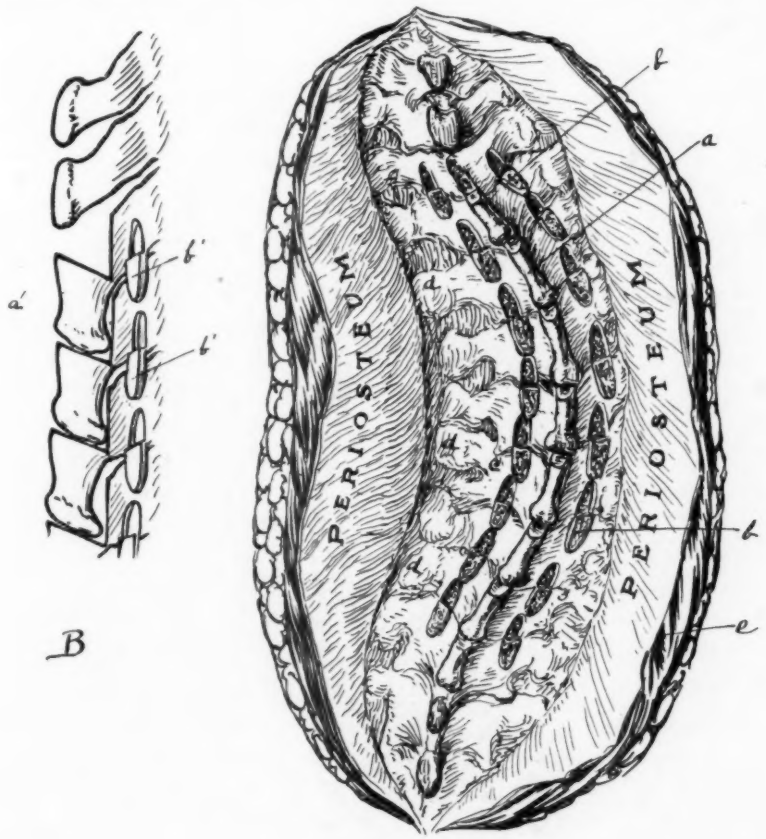

Fig. 3.—*A*, the Hibbs operation performed from the third to the tenth dorsal vertebra. The spinous processes (*a*) have been split and turned down, the tip of one being in contact with the base of the spinous process below; *b*, pieces of bone elevated from laminae and laid across the interlaminar spaces; *c*, articulation between articular processes scarified; *d*, tips of transverse processes, and *e*, spinal muscles. *B*, manner in which spinous processes are split and turned down (*a'*); small sections of bone elevated from laminae and turned down to bridge the space between adjacent laminae (*b'*).

the application of traction in the recumbent position on a convex frame. It has been my experience that there is a certain degree of potential improvement in every case. This degree varies in different subjects,

but when reached it seems impossible to progress beyond it. A given patient, for instance, is treated with corrective jackets. A marked change is seen in the first jacket; some further improvement is obtained in succeeding jackets. Finally, at the end of a year or more, no further change occurs no matter how much the treatment is prolonged, that is, the maximum degree of improvement for that case has been reached.

Fig. 4.—Beef bone graft inserted on concave side of curve. Upper part of graft held between split spinous processes of first and second dorsal vertebrae; lower part held between split spinous processes of eleventh and twelfth dorsal vertebrae. Nicks in graft to facilitate vascularization may be noted.

Experience has taught us about how much change we may expect in the various types of deformity, and one comes to depend on his experience in judging when the greatest amount of correction has been secured. My observations lead me to believe that the maximum potential improvement is secured by this method of traction applied in recumbency on a convex frame more rapidly and with very much less discomfort than by any other procedure. The correction obtained on the

frame would be of no advantage if at the end of the brief period of recumbency and traction the patient were permitted to get up without any further support, for relapse would occur immediately. The frame treatment is of value only as a preliminary step to some means of fixation of the spine. Operative fusion of the spine appears at present to be the most effective and most desirable method of fixation.

PREPARATION FOR OPERATION

As aseptic healing is particularly desirable, unusual precautions to avoid infection are taken in the preparation of both the patient's back and the graft to be used. A beef bone graft, cut to the desirable shape and thickness, is boiled for several hours and placed in a closed vessel with ether. Just before the operation it is again boiled for half an hour. Transverse nicks are made in the graft in the belief that these will facilitate vascularization. All traction and massage are discontinued three days before operation. On the first of these three days, the patient's back is shaved if necessary and scrubbed thoroughly with soap and water, dried, and a voluminous sterile dressing applied. On the second day, the back is again scrubbed with soap and water and covered with a sterile dressing. On the morning of the third day, or the day of operation, assuming that the patient is to be operated on in the afternoon, the back is painted with one-half strength (3.5 per cent.) tincture of iodin and a sterile dressing is put on. If the patient is to be operated on in the morning, the coat of iodin is used the night before. All of these details may perhaps be unnecessary, but they seem advisable, and inasmuch as I have not yet had an infection in a case of spinal fusion, I believe that these procedures have contributed some share, at least, to the satisfactory aseptic healing.

OPERATION

The operation, as I have performed it, combines the technic of the Hibbs and Albee methods. It includes most of the vertebrae of a simple curve and all of the vertebrae of the dorsal segment of a compound curve. The dorsal is the most favorable site for operation. This is so because the vertebrae are more easily reached in this region and because the elimination of motion here is of less consequence than in any other part of the back. An incision of the desired length is made through the skin and subcutaneous tissue. Following the method of Hibbs, the periosteum and overlying muscles are elevated from the spinous to the tips of the transverse processes, that is, the posterior arches of the vertebrae are thoroughly denuded and exposed. This part of the operation should be performed as nearly as possible subperiosteally, for troublesome hemorrhage is thus avoided. The joints of the articular processes are then scarified or destroyed. Chips of

bone are chiseled away from the laminae and placed across the interlaminar spaces. The spinous processes are split at their bases and turned down so that the tip of the spinous process above fits into the space at the base of the spinous process below. At times I have split the spinous processes into several horizontal sections which have been spread out into a fanlike mass (Forbes' method). When this part of

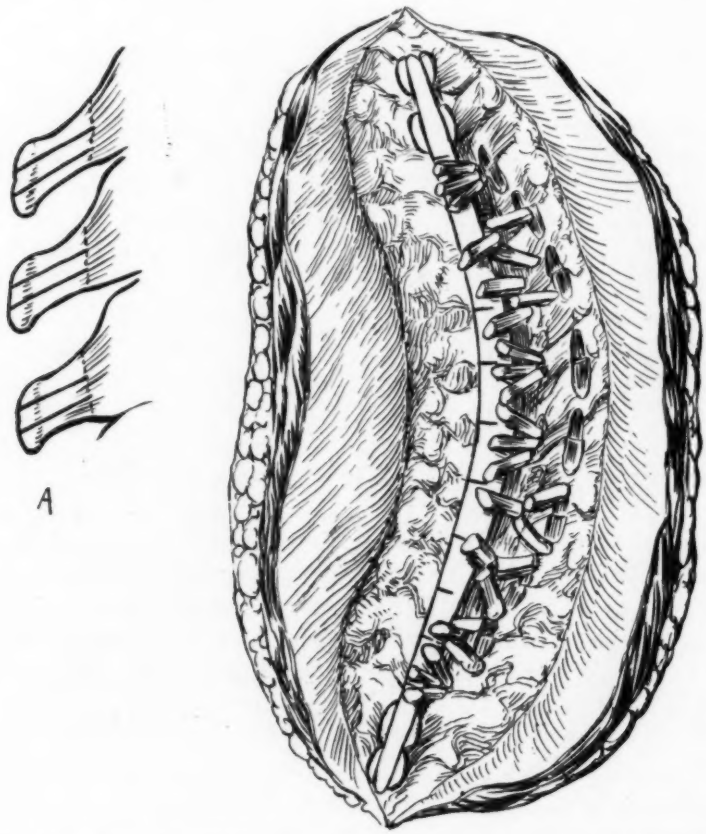

Fig. 5.—Spinous processes split according to the Forbes technic and the sections of the spinous processes laid in different directions, forming a large bony area for contact with the graft: *A*, lateral view showing manner of splitting spinous processes according to the Forbes technic.

the operation is complete, the spinous processes of two vertebrae above the upper limit and of two vertebrae below the lower limit of the curve are split (Albee technic). The latter vertebrae, being at the points of transition from the main to the compensatory curves, are rarely deformed to any degree, and the spinous processes are practically in the median line. A graft sufficiently long to reach between the limits of the vertebrae operated on, about one-fourth inch (6 mm.) wide and some-

what less in thickness, with a curve that corresponds to, but is not so marked as, the curvature of the spine, is laid in the wound, being placed on the laminae and transverse processes on the concave side of the curve, with the extremities of the graft embedded between the segments of the split spinous processes. The graft is thus brought into contact with a large mass of bleeding bone consisting of the transverse processes, laminae and spinous processes. When the spinous processes are split into several sections, I place them on top of the graft. They serve to hold the graft down and bring more of its surface in contact

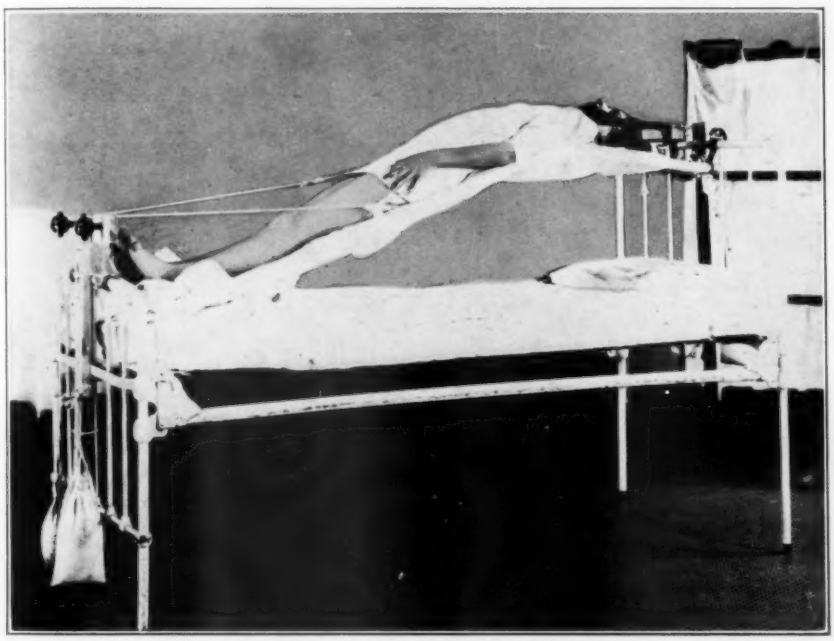

Fig. 6.—Arrangement of bed and convex frame used in the treatment of scoliosis at the Hospital for Ruptured and Crippled.

with living bone. The periosteum and muscles are sewed with interrupted kangaroo sutures. The subcutaneous tissue and skin are closed with separate layers of catgut. A dressing is applied and a warm sterile flannel jacket is put on and the patient returned to bed.

RATIONALE OF THE OPERATION

Experience has shown that it is very difficult and often absolutely impossible, as well as dangerous, in the *severe cases* of scoliosis completely and thoroughly to denude the posterior arches of the vertebrae of periosteum; that is, it is not possible to perform the typical Hibbs operation. I have, therefore, used a stout bone graft with two objects

in view. First, as a strong mechanical support extending between the ends of the curve, the graft will prevent increase of the curvature during the healing and consolidation. Second, as in the course of time this huge mass of bone is absorbed, it will be replaced by new bone so that there will be in the region of the curvature a very large and solid mass of bone (greater perhaps than results from the simple Hibbs fusion) which will join the vertebrae, prevent increase of deformity

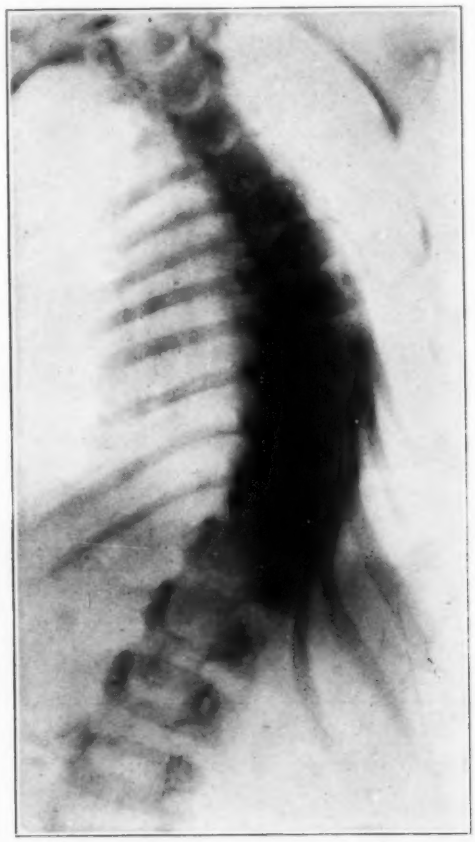

Fig. 7.—Roentgenogram of boy (S. P.) with paralytic structural scoliosis, taken, May 22, 1921, a few days before he was placed on the frame.

and thus be instrumental in arresting the progress of the deformity. Whether the hoped-for result will be obtained remains to be proved.

POSTOPERATIVE CARE

The operation, involving as it does rather rough handling of the vertebrae, pulling, pushing, scraping, chiseling, hammering, some bleeding and an anesthesia of not less than an hour, and usually nearer an hour and a half, is accompanied practically always by some shock.

The patient is, therefore, put back to bed and not on the frame. When extra heat is necessary, it is supplied by means of therapeutic lamps and portable baking machines. This simple, but very helpful, procedure was suggested by Armitage Whitman. Extra blankets are supplied and, if necessary, medication. It usually takes three or four days before the patient begins to feel comfortable and the pulse returns to the preoperative normal.

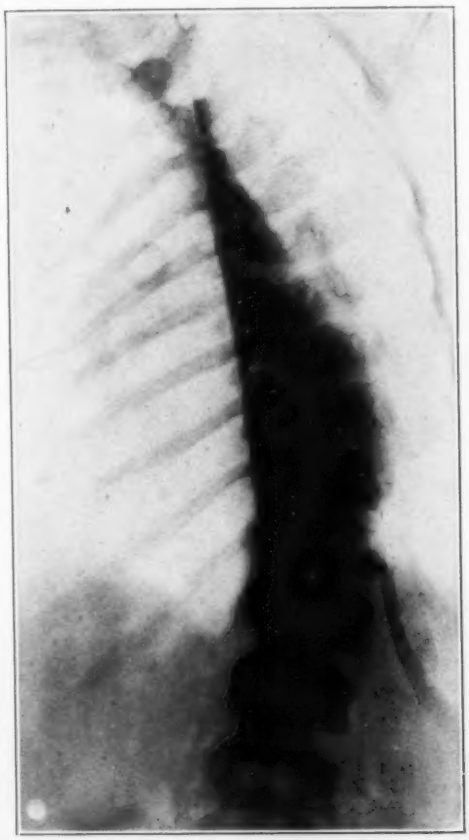

Fig. 8.—Patient (S. P.) treated on frame until July 19, 1921, when he was operated on. This roentgenogram was taken, Sept. 22, 1921, while he was still on the frame and shows reduction of curve of spine and graft in place. The improvement in the appearance of the back is greater than the apparent reduction of the curvature of the spine.

When the patient has completely recovered from the immediate effects of the operation, that is, in a week or ten days, she is replaced on the frame. Traction is applied so that the maximum degree of improvement of the back is retained while consolidation and bone for-

mation are taking place. It is hoped then that the union or fusion of the vertebrae will take place with the spine in the most favorable and least curved or deformed condition. This usually means a postoperative period of treatment of not less than eight weeks. During this time, the patient receives massage and exercises of the limbs.

At the end of this period, we have found that the patient is usually able to stand up and retain the improvement. Fearing, however, that

Fig. 9.—Case (M. J.) of idiopathic structural scoliosis, July 21, 1921, treated by corrective exercises for one year. Deformity growing worse.

the union may not be sufficiently solid, additional support in the form of a light, well-fitting plaster jacket is continued for several months.

The entire treatment lasts between six and nine months, and I believe that in this comparatively short period the same results may be accomplished as were formerly obtained by the corrective jacket method in several years, and with the likelihood that there will not be any relapse.

Although the operation does not remove those particular factors (whatever they are) which are responsible for the rotation and deviation of the vertebrae, and although it is appreciated that a solid spinal column may, like a single long bone, such as the tibia or femur, become deformed, yet it seems reasonable to believe and we are encouraged in this belief by our recent experience that when from eight to twelve vertebrae are fused into a solid mass, there will be little, or less, tendency toward increase of deformity.

RESULTS OF TREATMENT

Our experience with the system of treatment outlined has not extended over a sufficiently long period, nor does it include a large enough series of cases, to permit absolutely positive conclusions; but the results have been highly satisfactory and justify its use on a large scale. The preoperative, or corrective, treatment affords an opportunity to obtain the same degree of improvement resulting from the employment of other methods and has the distinct advantage of taking very much less time than is necessary when using jackets, braces or exercises. In addition, it is entirely free from the restraint and discomfort of jackets or braces. Atrophy of the muscles may be avoided by daily massage and exercise on the frame. The permanency and value of fixation of the spine must be left to future judgment.

The immediate results have been satisfactory in all of the cases. The appearance of the back has been improved. In all but one case, the curvature of the spine was reduced. In the one case, that of a girl, aged 17, with an extremely severe scoliosis, the curve of the spine was not reducible. The operation was performed because the deformity was becoming more severe and it was hoped that the spinal fusion would "fix" the spine and prevent increase of the curvature. This patient has already gone without any support for several months and so far the deformity has not increased. Five other patients of my series have been without any support for periods varying between two and six months and have retained the improvement. In these cases, the fixation has been successful, for the operative region of the spine remains immobile. In two instances, there is noticeable fragmentation and partial disappearance of the graft. As there is no large amount of callus (as far as one may judge from roentgenograms), it is impossible to say whether the graft has been replaced by new bone. However, the stiffening of the spine persists.

Up to date, I have operated on nineteen patients, twelve girls and seven boys. The ages varied between 8 and 20 years. Three cases were paralytic and the others were of the idiopathic type. I believe that fixation and at least fibrous ankylosis were obtained in every instance. Fixation of the spine was judged clinically by the loss of motion. The

loss of flexion and extension was determined by the lack of motion in the anteroposterior plane when the lumbar region was immobilized. It was difficult to decide about the absence of lateral motion in the dorsal region, because it was hard to eliminate, by ordinary manual support, all lateral motion between the lumbar vertebrae. Roentgenograms were used to help us in this connection. They were taken with

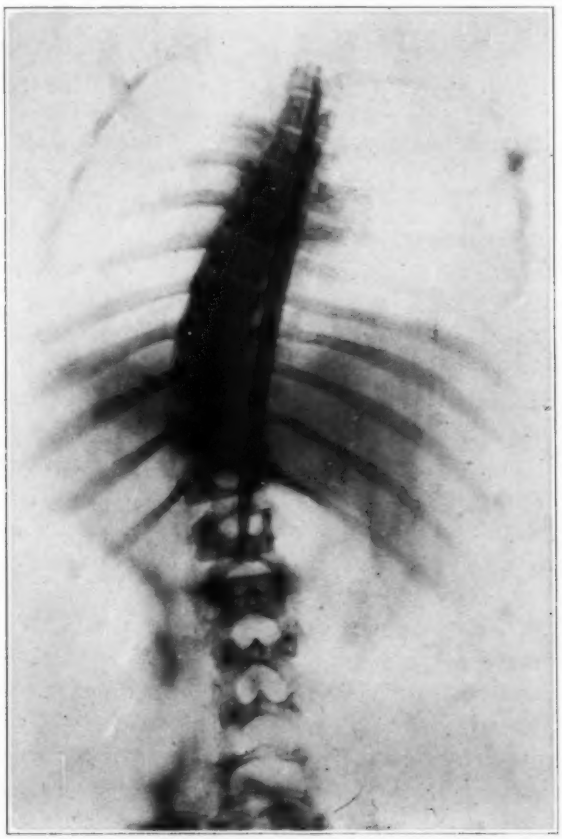

Fig. 10.—Same patient as in Figure 9, treated on convex frame from July 21, 1921, to Sept. 13, 1921, when he was operated on. This roentgenogram, taken Oct. 10, 1921, while the patient was still on the frame, shows reduction of curve and graft in place.

the patient bent laterally, first to the extreme right and then to the extreme left. In several cases in which this test was used, there was apparently no lateral motion between the vertebrae operated on, and the fixation was seemingly complete.

It has thus far been impossible to judge from the roentgen-ray appearance alone whether there was osseous fusion of the vertebrae.

In none of the cases was there any large amount of bone thrown out at the site of operation. But in a number of instances, there was marked haziness and partial obliteration of the intervertebral spaces. This was interpreted as signifying deposition of new bone, presumably uniting the posterior arches.

As previously mentioned, we have not limited ourselves to paralytic cases and we believe that the treatment is applicable to all varieties of scoliosis. It is manifestly not indicated in a case which has remained stationary for a number of years; nor should an operation be performed on a patient who is so markedly deformed that she is not likely to become worse. To be of the greatest value, the operation should be performed in the mild cases, so that the more advanced degrees of deformity may be prevented.

SUMMARY

The treatment of structural scoliosis by the method outlined, consisting of a period of correction by means of traction on a convex frame followed by operative fixation of a large number of vertebrae by denuding the periosteum from the posterior arches of the vertebrae and inserting a large and long beef bone graft, has given very satisfactory results and appears to be a distinct improvement and advance in the management of this most troublesome of all deformities.

The use of the beef bone graft has many advantages. It may be prepared in advance, so that the operation is not needlessly prolonged. It may be cut of the desired length, shape and thickness. It affords support during consolidation of the vertebrae on which operation has been performed. It acts as a framework for new bone formation. It is especially valuable in the severe cases in which the deformity of the ribs and vertebrae is so marked that it is impossible and unsafe to carry out the Hibbs fusion operation thoroughly.

The discomfort and disadvantages of plaster-of-Paris jackets are avoided and the surgeon is spared much hard work. The entire period of treatment is very much shortened, and it is hoped that it may not exceed nine months. Corrective treatment can be carried out more rapidly and just as efficiently on a convex frame with traction as by plaster-of-Paris jackets or braces.

Finally, the results obtained compare more than favorably with those following the use of plaster-of-Paris jackets, braces or gymnastic exercises.

BONE REPAIR FOLLOWING INJURY AND INFECTION *

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Since McEwen's classical work on bone repair, there has been much uncertainty in the minds of clinicians regarding the process that occurs in bone repair following injury. Whether or not the periosteum is the all-important factor in osteogenesis has clouded our minds. The significance of the bone cell, of the periosteum, and the significance of intermembranous or of intercartilaginous bone development is not known. The terms after long usage are established as entities, thus tending to suggest biologic differences because of microscopic difference. Until the physical chemist gets at the root of things, confusion concerning bone in all parts of the body will exist in the minds of laboratory workers. I believe when the real secrets of bone formation are understood, we shall acknowledge that osteogenesis occurs in the same manner in all tissues. The tissues that are seemingly different under the microscope, I believe, are chemically similar whenever osteogenesis occurs, be it repair in a fracture or repair following infection, be it in periosteum, in muscle planes, in artery wall or in the ventricular septum of the heart. Stop and think of the confusion which necessarily follows, when at best only microscopic sections can be seen of the various complex tissues manifesting bone formation at single stages of each experiment. The physiologic chemist is handicapped in the same manner because his analysis by necessity is of a single stage, always involving many tissues. In the human being, and in the laboratory animal used for experiment, the tissues are far too complex in their functional activities and structural make-up to make it possible for the observer to deduce what happens in single cells such as may be present in osteogenesis; hence, the confusion among experimenters as expressed in the literature. The surgeon is too likely to feel that he does not know much about bone repair because he is so confused by the differences of opinion of the various experimenters. Those interested in osteogenesis are as often as not disputing over names and terms rather than discussing processes, and bone formation is truly a process and not a state.

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* From the Laboratories of the Department of Surgery, Columbia University College of Physicians and Surgeons.

* Read before the Annual Meeting of the Colorado State Medical Society, Pueblo, Oct. 6, 1921.

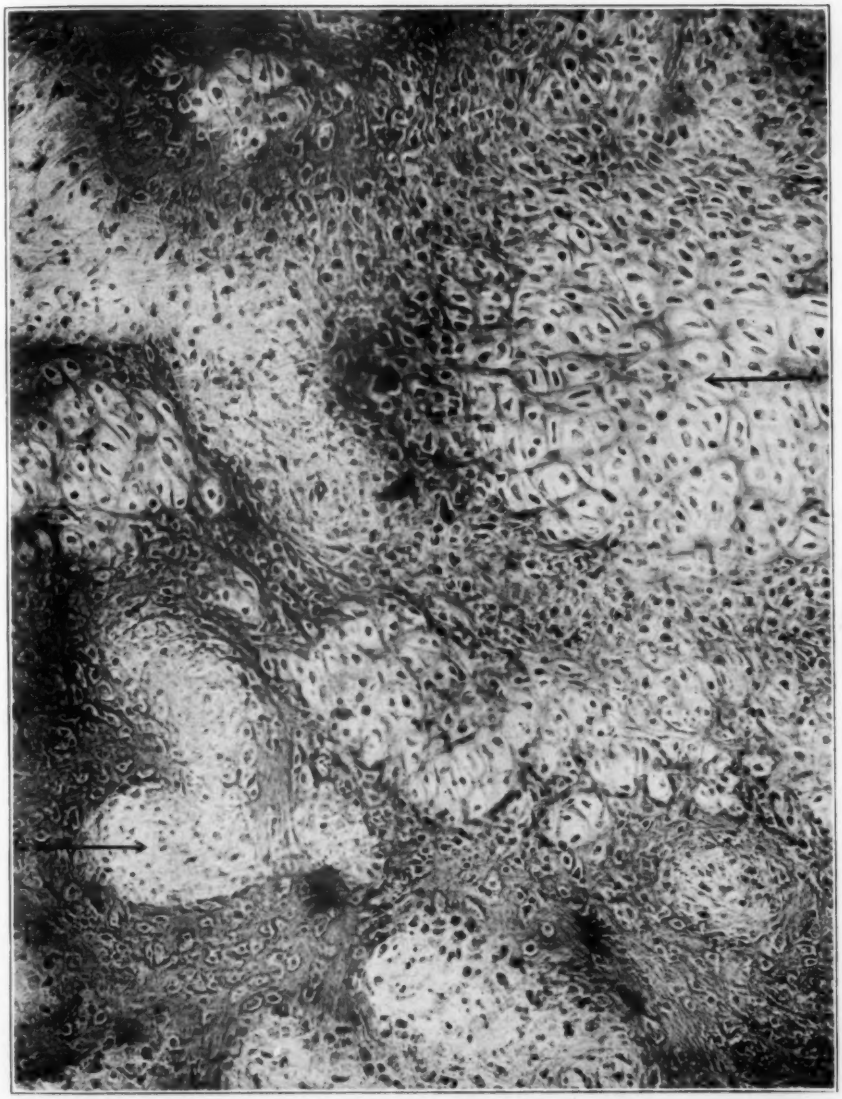

Fig. 1.—Early bone formation following fracture: *A*, cartilage; *B*, new bone; *C*, connective tissue. Gradual transitions are observed from connective tissue to cartilage, from connective tissue to bone and from cartilage to bone. No distinctive cells are seen.

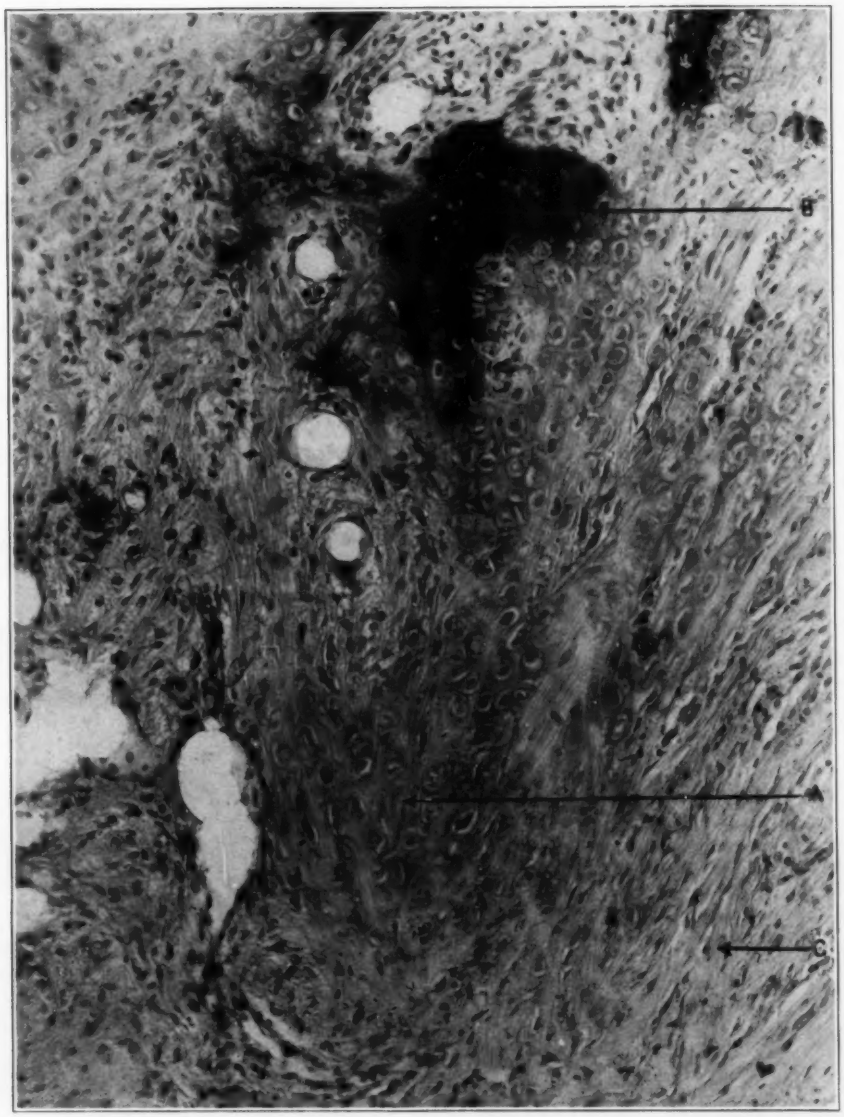

Fig. 2.—Scrapings removed from fractured humerus of a human being, twelve days after injury: *A*, fibrocartilage; *B*, early bone; *C*, connective tissue.

Fig. 3.—Ossification occurring in the midst of muscle fibers, twelve days following a fracture of the humerus in an adult: *A*, ossification occurring in cartilage; B, early bone; C, connective tissue; D, degenerating muscle fibers.

Fig. 4.—Callous formation seventeen days following fracture, showing deposition of calcium salts on the avascular zones in early connective tissue.

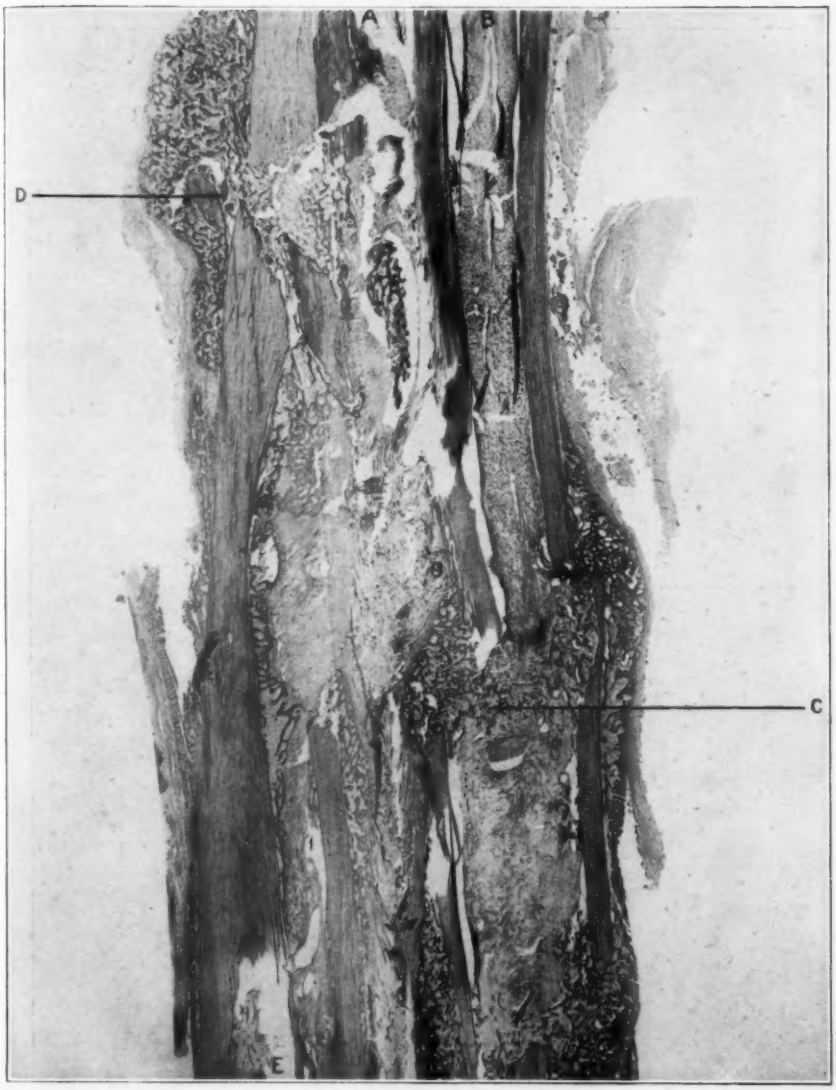

Fig. 5.—Comminuted fracture of radius and ulna in rabbit, fourteen days after injury: *A*, interosseous membrane; *B*, medullary canal of radius with cortex on either side; C, new bone forming in connective tissue following hemorrhage around the fractured ends and across the medullary canal; *D*, detached bone fragments surrounded by new bone formation; *E*, medullary canal of ulna.

Fig. 6.—High power magnification of radius and ulna shown in Figure 5: *A*, end of fractured shaft showing atrophy at end with absence of bone nuclei; *B*, new bone formation in the connective tissue; *C*, areolar connective tissue with newly formed blood vessels.

Fig. 7.—Bone transplants four weeks following operation: *A*, haversian canal with reestablishment of blood supply and surrounded by one or two layers of active bone nuclei; *B*, absence of nuclei in bone distant from haversian canal.

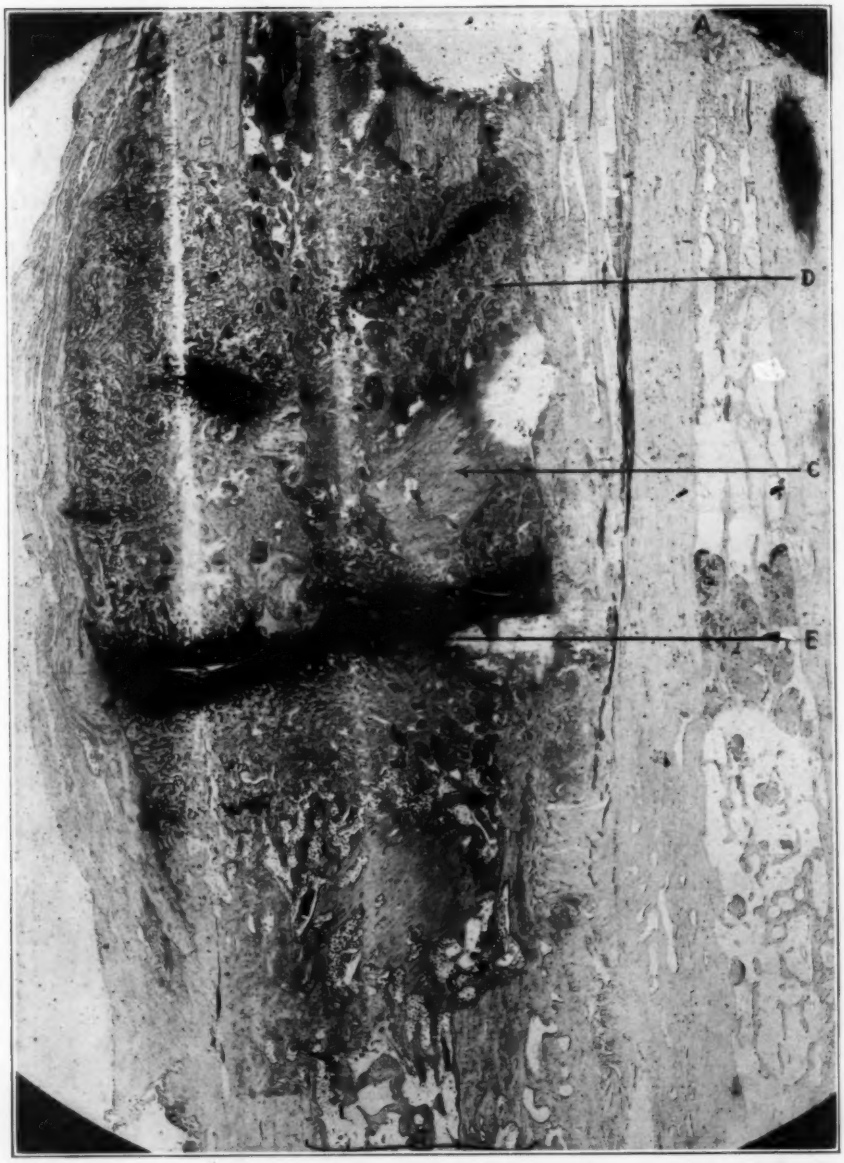

Fig. 8.—Transplantation of bone fragments to fill defect in radius, 141 days following operation: *A*, ulna; *B*, radius; *C*, bone fragment; nuclei do not stain; areas of rarefaction near periphery; *D*, new bone formation about periphery of fragments; *E*, cartilage forming false joint.

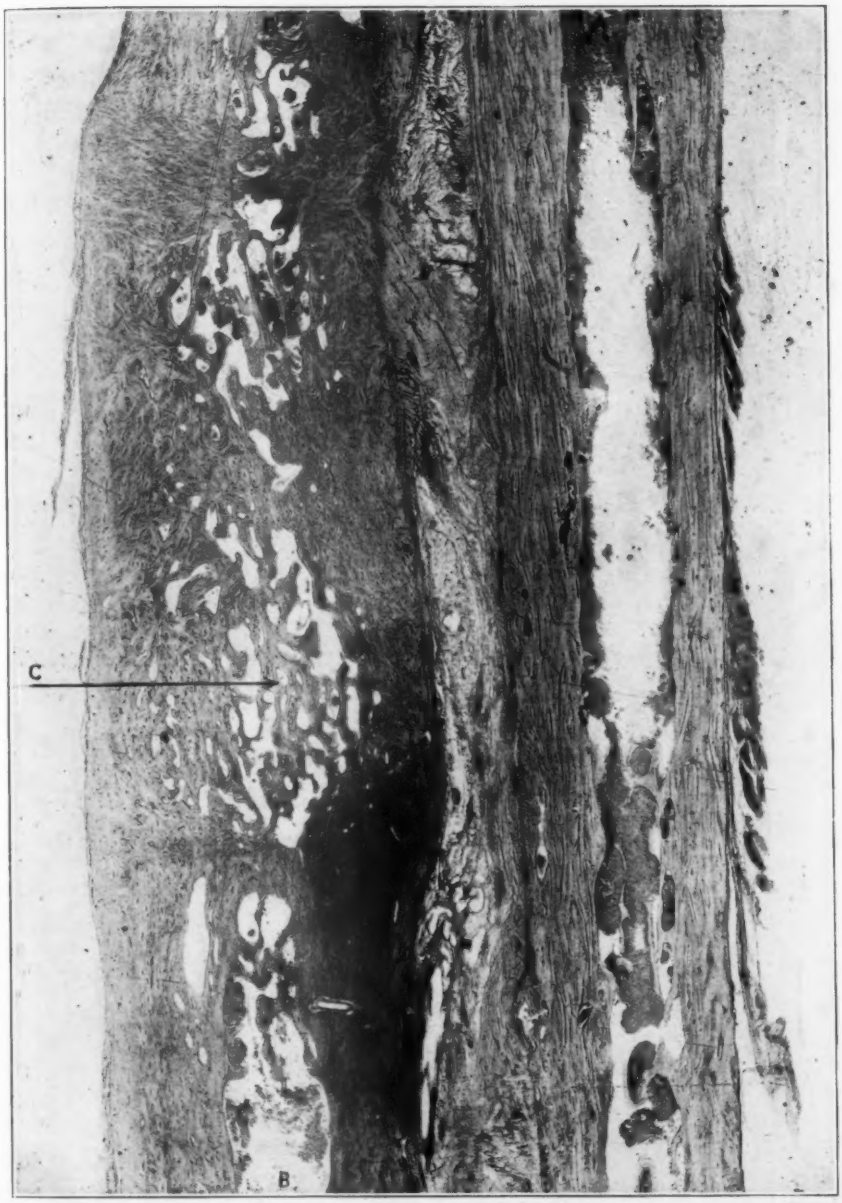

Fig. 9.—Transplantation of bone fragments to fill defect in radius, 347 days following operation: *A*, ulna; *B*, radius; *C*, beginning formation of medullary canal. The entire zone shown in the illustration is the area in which the transplants were placed. It is no longer possible to detect the fragments; but a new cortex and medullary canal are being established by the gradual absorption of the fragments and the formation of new bone.

In order to have satisfactory therapeutic results, it is advisable to accept some practical working theory that will cover all types of bone formation. This theory should be broad enough not only to cover the skeletal bone formation but also the extraskeletal bone formation

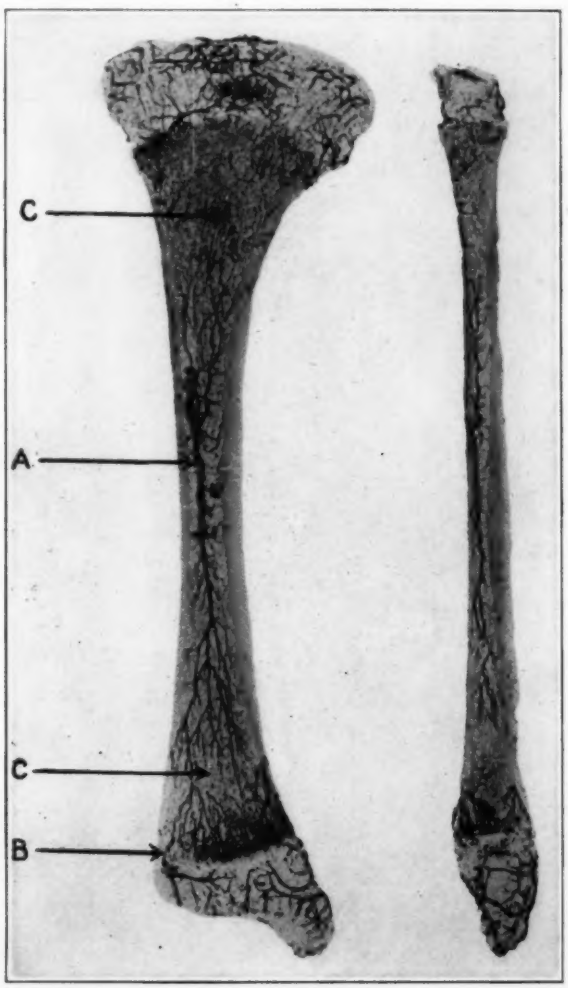

Fig. 10.—Circulation of infant's tibia and fibula (after Lexer): *A*, nutrient artery; *B*, metaphyseal capsular artery; *C*, relative avascular zone, where sequestrum separation usually occurs.

that occurs in so many places in the body. Extraskeletal bone formation occurs in one or more tissues in all of us if we live long enough. and it may be produced experimentally in animals without difficulty Extraskeletal bone occurs frequently in man in the arterial wall and

in the muscles. It has been described as having been found in nearly all of the tissues of the body, such as the lymph nodes, ovaries, kidneys, fascial planes and wall of the orbit.

Experimentally, bone has been produced in animals by ligating the vessels of the kidney and wrapping the omentum about it. Microscopic sections of this kidney from one to two months later show areas of true bone and calcification occurring in the parenchyma. Neuhoff,

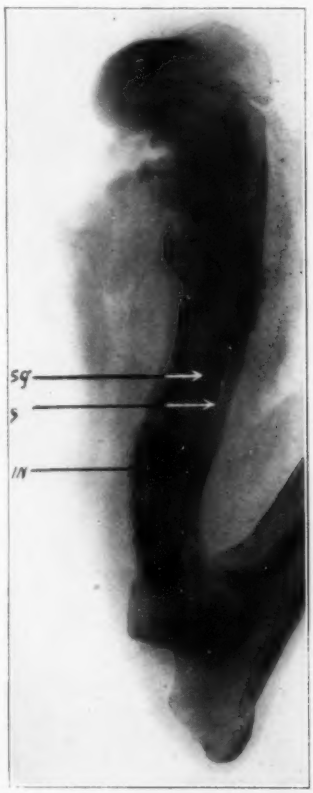

Fig. 11.—Roentgenogram of humerus, Nov. 3, 1919. Croton oil was inserted into the medullary canal in capillary tube containers, Oct. 10, 1919: *SQ*, sequestrum; *In*, involucrum; *S*, separation zone.

working in the laboratory of surgical research at Columbia University, found bone almost universally in fascia lata transplants that he had made to fill a defect in the bladder. Any theory, therefore, that we may accept should be broad enough to explain these irregular types of bone formation as well as the repair of bone following fractures and infection. We may, for the sake of discussion, classify the theories of bone repair roughly into three groups: (1) periosteal; (2) osteoblastic, and (3) extracellular deposition of calcium salts.

1. The periosteal theory presupposes that the periosteum and endosteum are definite organs for bone formation and repair, and that the bone cells arise from them and from no other source.

2. The osteoblastic theory may be divided into two subtitles.

Type A. This assumes that in bone repair following injury bone cells are liberated from their lacunae and that they reproduce and form new bone.

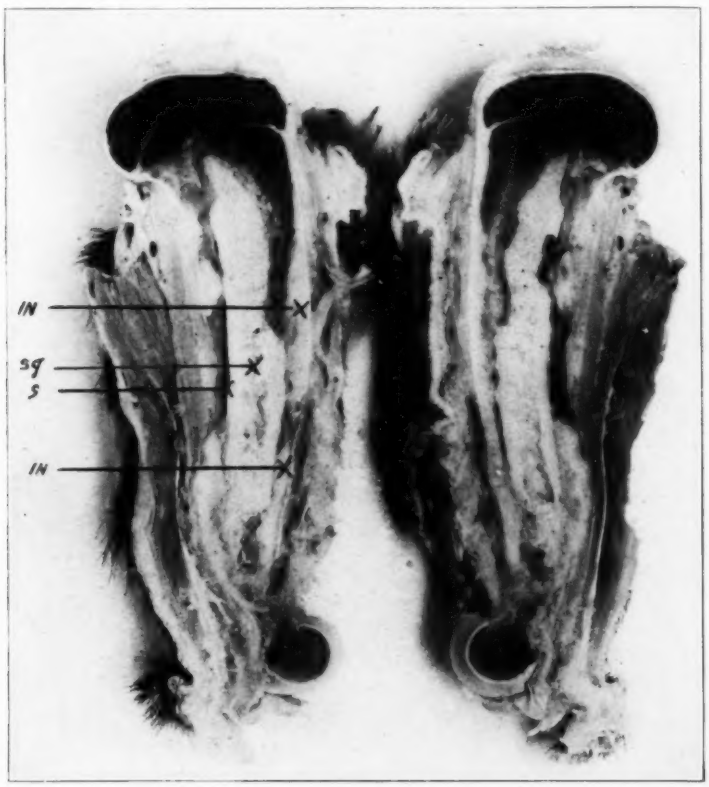

Fig. 12.—Cross-section showing massive sequestrum extending almost the entire length of the shaft; *SQ*, sequestrum; *In*, involucrum; *S*, separation zone.

Type B. This assumes that following injury wandering connective tissue cells, fibroblasts, are drawn into the area of trauma. Owing to the stimulus of the repair, they are transformed into bone producing cells and then become specific cells.

3. The extracellular deposition of calcium salts theory assumes that there is no definite bone producing cell; that following injury, possibly by positive chemotaxis, calcium salts in the proportions usually found

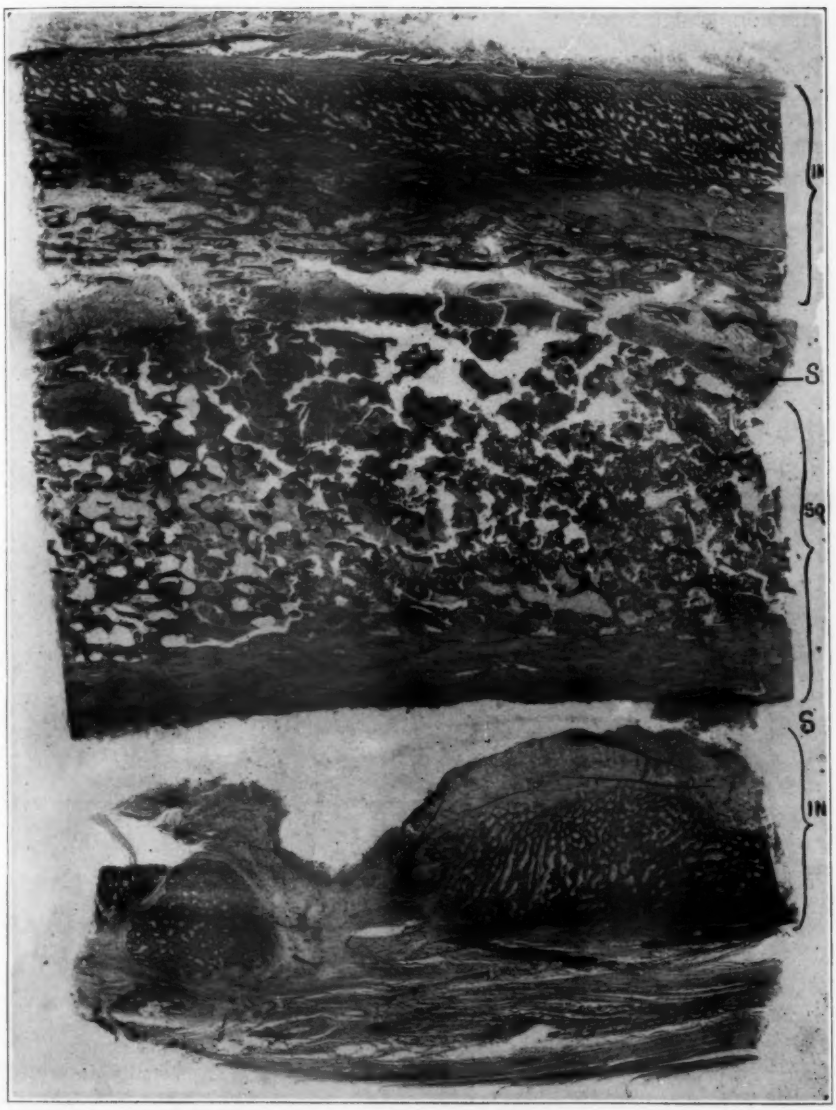

Fig. 13.—Microscopic section: *Sq*, sequestrum; *In*, involucrum; *S*, separation zone. Under high power magnification the bone nuclei in the sequestrum are absent and the zones in the medullary canal are filled with leukocytes. The separation zone *S* contains débris and numerous polymorphonuclear leukocytes. In the lower separation zone *S*, débris disappeared during the process of decalcification.

in bone are deposited in the extracellular frame-work of connective tissue and that the connective tissue cell then becomes a bone cell by functional adaptation.

Any one of these three theories may explain the ordinary repair of bone as seen in fractures; but it is difficult to explain under the periosteal theory the formation of extraskeletal bone.

The bone in fascia lata transplants in the bladder found by Neuhoff cannot be explained by the periosteal theory, and it is difficult to explain

Fig. 14.—Following insertion of capillary tube containing croton oil, in medullary canal, Sept. 21, 1920. Roentgen ray. Large sequestrum in upper half of humerus, Oct. 15, 1920.

it if we assume that the osteoblast is a specific cell coming from other bone cells. Moreover, it is impossible to explain the formation of bone in the arteries of human beings, in the lymph nodes or in the kidney by either of these theories.

If we assume that bone is formed by metaplasia of connective tissue cells into osteogenetic cells or if we assume that it is purely a chemical deposition in living connective tissue, we may explain the phenomenon very easily.

The third theory has seemed more plausible to me. Gideon Wells has shown that if cartilage is transplanted into the omentum it has a greater power of absorbing calcium from the blood than has any other tissue similarly placed. He believes that the same proportions of calcium phosphate and calcium carbonate are present in the ash of calcified material as bone, the main difference being that calcification occurs in dead tissue while ossification occurs in the presence of living tissue. In sections of kidneys in which the vessels have been ligated,

Fig. 15.—Cross-section showing massive sequestrum, with thick involucrum and zone of separation: *SQ*, sequestrum; *In*, involucrum; *S*, zone of separation.

there are zones of calcification and ossification, the calcification occurring in dead tissue and ossification occurring where living bone cells are observed.

The simplest type of bone repair is seen following fractures. In a series of fractures on animals, I have been able to follow the repair at various stages. Immediately following the fractures, there is hemorrhage between the broken ends. Fibrin is then deposited and con-

traction of the clot occurs. In from about five to ten days the organization of the clot by the ingrowth of connective tissue occurs. Connective tissue appears to take a definite lobulated arrangement, so that if we look at a cut section, we find blood vessels and then areas of thin areolar connective tissue (Figs. 1 to 4).

Calcium salts are then deposited in the avascular zones between the blood vessels. Early callus looks very much like the lobules of the

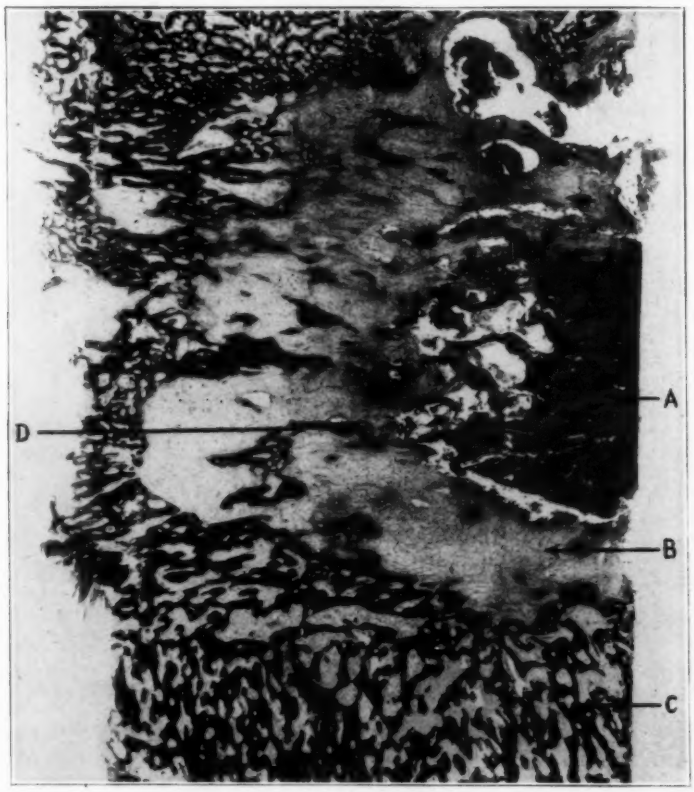

Fig. 16.—Lower power magnification of terminal portion of sequestrum with surrounding involucrum: *A*, sequestrum; *B*, granulation tissue; *C*, involucrum; *D*, terminal spicule of sequestrum shown under high power in Figure 17.

liver. At first the blood vessels appear about this area of areolar tissue and then an area of new bone appears. At a later period, the areolar zone is almost completely replaced by osteogenetic tissue. This process continues until there is a definite haversian canal system of adult bone. In the zones of exuberant callous formation, absorption of the calcium salts takes place and scar tissue results. Bone atrophy occurs almost universally near the fractured ends. A great number of nuclei of the bone cells in the lacunae disappear.

Fig. 17.—Terminal portion of sequestrum showing new bone formation about it, and gradual reorganization: *A*, dead bone, cell spaces are empty showing no nuclear stain; *B*, newly formed bone surrounding and incorporating dead bone.

As the granulation tissue springs from the periphery and the new blood vessels run at right angles to the shaft, the haversian canals as seen by microscopic examination from three to five months following fracture, are perpendicular to the normal haversian canals of the shaft. At the end of a year, however, by a gradual process of absorption and new formation, canals are reestablished in a normal direction. Periosteum, as it is a connective tissue and as it has an areolar layer

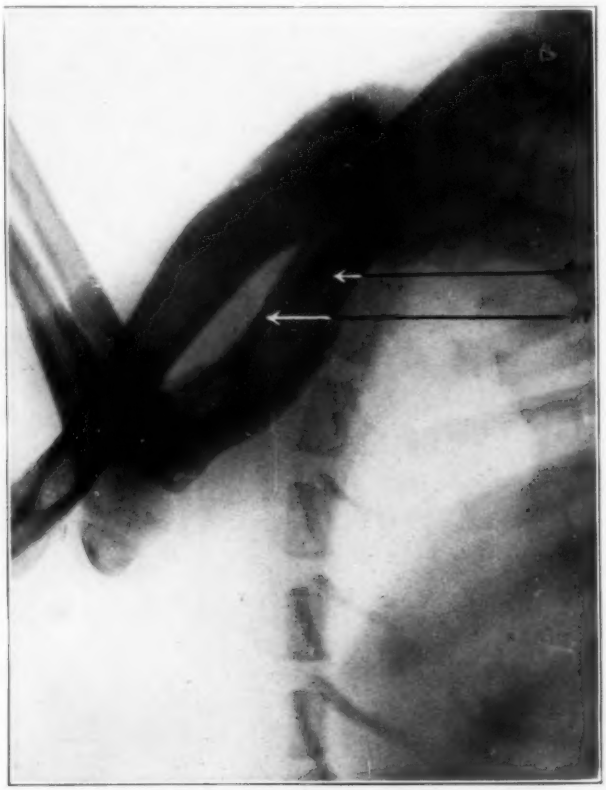

Fig. 18.—Large sequestrum, Nov. 10, 1919, with well marked involucrum and separation zone: *In*, involucrum; *Sq*, sequestrum; operation performed, Oct. 10, 1919.

immediately adjacent to the shaft, undoubtedly serves as a bone forming membrane; but it is not the only connective tissue which may form bone (Figs. 5 and 6).

The study of bone grafts shows strikingly why the clinician and the laboratory worker have differed in their accounts of the after-history of the graft.

The clinician has usually stated that grafts "live," because if occasion should arise demanding the performance of a secondary operation,

he finds that the cut section of the graft bleeds and that it has the general appearance of living bone. Roentgenograms also show the graft appearing as normal bone.

The laboratory worker on microscopic examination finds that in grafts of one to two weeks' duration the nuclei do not stain and the bone appears dead. Microscopic examination at a later period reveals the blood vessels reestablished in the haversian canals, and about them one or two layers of living bone cells, while portions of the graft

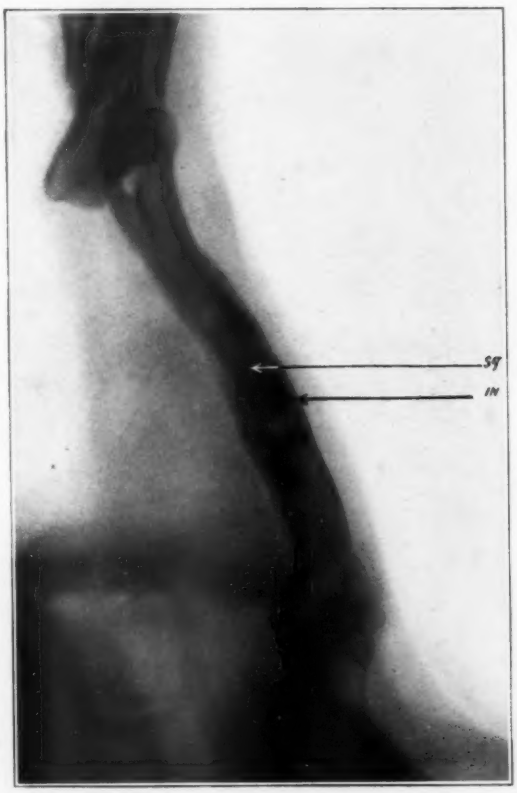

Fig. 19.—Sequestrum and involucrum, Dec. 1, 1919, less marked than previously: *In*, involucrum; *Sq*, sequestrum.

further from the canals show the absence of nuclei (Fig. 7). The process then continues as a gradual absorption of the dead bone and the formation of new bone in its place. It is easy to see that the bone at this period would bleed on section and would appear alive clinically.

In order to have a successful graft, three conditions must be established: First, the graft must maintain the shape of the limb; second, it must have its blood supply quickly reestablished and, third, it must stimulate osteogenesis in the neighboring tissues.

McWilliams, in a thorough analysis of the various methods of bone grafting, read before the American Surgical Association at Toronto in June, 1921, came to the conclusion that the presence of periosteum upon the graft had very little influence upon its ultimate success. He analyzed about 1,390 cases in which grafts had been used. Of these, 1,170, with 82.9 per cent. of successes, had periosteum, while 196, with 82.6 per cent. of successes, were without periosteum. In

Fig. 20.—Roentgenogram, Jan. 15, 1920; no involucrum or sequestrum seen.

analyzing the types of transplants, he found that the successes were relatively as follows: bone pegs, 95.8 per cent.; osteoperiosteal (Ollier, DeLangeniere), 87.3 per cent.; end-to-end (without inlay), 82.5 per cent.; inlay, 80.9 per cent., and intramedullary, 76.6 per cent.

If we study these, we find that probably the three points emphasized for the success of bone grafts explain the relative success of the foregoing methods.

Bone pegs are surrounded completely by bone and very quickly have their blood supply reestablished.

The osteoperiosteal grafts of DeLangeniere are thin strips of bone and periosteum which are laid down between the ends of the bone. If they are sufficient to maintain the shape of the limb, theoretically they are the most practical, for the blood supply is very quickly established. They offer a large surface of raw bone to stimulate osteogenesis.

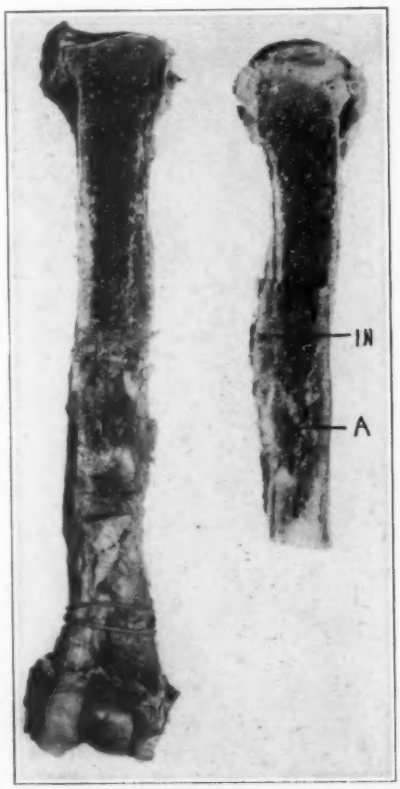

Fig. 21.—Cut-section, Jan. 24, 1920: *In,* subperiosteal bone proliferation; *A,* probable remnants of old sequestrum but no separation zone.

The inlay graft is, as a rule, rather thick and does not offer so much surface of raw bone for stimulation of osteogenesis. The late fractures that occur in these cases are probably due to the slow reestablishment of the blood supply and the resulting atrophy of the transplant.

I am inclined to believe that the intramedullary graft should be condemned. We know that the main blood supply of the shaft of the long bone is from the nutrient artery. In applying an intramedullary

graft, we destroy the blood supply of both fractured ends of the shaft and undoubtedly a longer time is required for repair on account of this to reestablish the blood supply of the graft.

In a series of experiments lasting over two or three years, I transplanted small bone fragments into a defect of from 1 to 2 inches (2.5 to 5 cm.) in the radii of dogs. Microscopic studies made at various intervals after operation showed, in the early stages, absence of the nuclei in all these grafts. There was, however, marked production

Fig. 22.—Microscopic section showing subperiosteal bone proliferation, no zone of separation: *A*, spaces in which capillary tubes lay; *B*, artefact occurring during decalcification.

of new bone about them in the granulation tissue produced immediately after operation. Firm union was the ultimate result in nearly all of these cases.

At the end of about a month, blood vessels were seen in the haversian canals of the fragments, and about each of these canals were seen two of three layers of bone cells with active nuclei. I believe that these grafts act in a manner similar to the osteoperiosteal grafts of DeLangeniere (Figs. 8 and 9).

OSTEOMYELITIS

At the present time, when radicalism is necessary in the treatment of chronic osteomyelitis in adults, I believe a word of caution should be spoken with regard to the treatment of hematogenous osteomyelitis in children.

Fig. 23 (Case 1).—Roentgenogram, taken July 30, 1919; operation performed June 22, 1919, consisting of removal of 2 inches (5 cm.) of anterior surface of the upper third of the tibia: *A*, area of bone removed at primary operation; *In*, involucrum; *S*, separation zone.

The treatment of acute osteomyelitis in children may properly be divided into the treatment at the acute, and treatment at the subacute, stage. The primary indication for operation at the onset is the relief of pus under pressure, and as such, it requires the application of the

same surgical principles as pus collections elsewhere in the body, that is, adequate drainage, with the least possible trauma and with careful attention to the blood supply. If one considers that frequently periosteum with its blood supply has been stripped from the shaft by the exudation of pus and that the only remaining blood supply to the shaft is through the nutrient artery, one realizes the danger to the entire shaft of too active treatment by curettage or packing (Fig. 10).

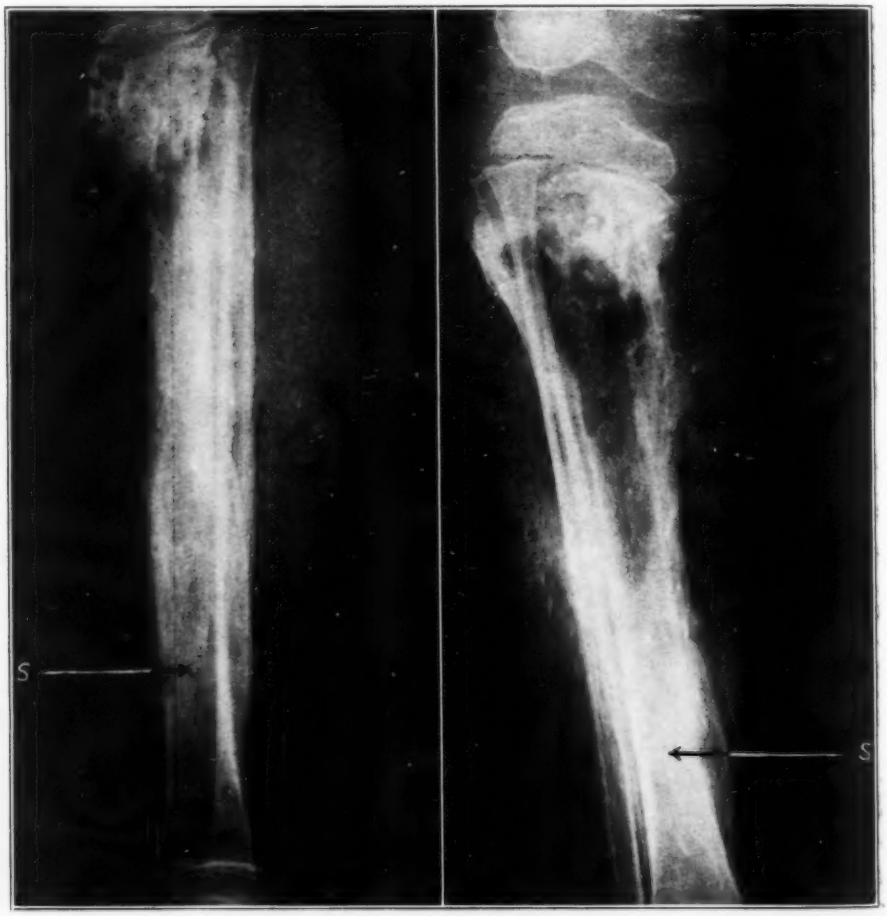

Fig. 24 (Case 1).—Operation, June 22, 1919; roentgenogram taken Aug. 22, 1919: *S*, former separation zone; marked subperiosteal proliferation. No operative procedure has been performed on this area.

It is true that in the region of the metaphysis, the bony septums somewhat resemble the septums of the mastoid, and that, therefore, in this region it may be necessary to break up the compartments of the abscess. Care should be taken even here not to traumatize any more than possible.

Constant, careful postoperative observation of these cases is necessary, as there are frequent secondary metastatic abscesses in the soft parts.

Subacute Stage.—Before the days of wound sterilization, the course of a case could be fairly definitely prophesied. At the primary operation, the shaft was opened wide, frequently curetted and packed. Following this, sequestration occurred, frequently involving almost the entire shaft. As advised by Nichols, of Boston, the sequestrum was usually removed at a time when the involucrum was strong enough to

Fig. 25 (Case 1).—Operation, June 22, 1919; roentgenogram taken, Nov. 24, 1920; no sinus; patient apparently well.

maintain the shape of the limb, and yet, at such a stage when the involucrum could be inverted, obliterating, as far as possible, the "dead space."

In 1919, I attempted to reproduce osteomyelitis in dogs before the students of the third-year course in regional surgery at Columbia. At the suggestion of Dr. William C. Clarke of the department of surgery, through a drill hole in the cortex of the medullary canal of the humerus,

croton oil was introduced in glass capillary tube containers having their ends sealed with agar-agar. The hole in the cortex was then plugged with bone wax, and the soft parts and the skin were sutured. By this procedure, repair following the operative trauma was allowed to progress before the croton oil was liberated from the capillary tube, probably by the solvent action of the cells and body fluids upon the agar-agar. As croton oil causes marked necrosis of the surrounding bone, we were able to produce a chemical osteomyelitis. A sequestrum,

Fig. 26 (Case 2).—Roentgenogram taken, Dec. 8, 1919, previous to operation: *Sq*, sequestrum; *In*, involucrum; *S*, separation zone.

often from 5 to 10 cm. in length, and including the entire circumference of the shaft, frequently occurred (Figs. 11 to 17). This sequestrum was separated from a newly formed involucrum by a zone of débris and leukocytes; therefore, all the factors of an acute osteomyelitis were present with the exception probably of bacteria and their by-products. Sections showed the sequestrum with an involucrum surrounding it but separated from it by a zone of pus. The cortical bone of sequestrum showed absence of nuclei, and throughout its cancellous portion there

was a marked infiltration of leukocytes. The involucrum consisted of newly formed subperiosteal bone.

In the prolonged animal experiments roentgenologic studies showed the gradual disappearance of the sequestrum so that at the end of two months it was impossible to detect its former outlines by the roentgen ray (Figs. 18 to 22). Microscopic sections taken at this time showed the disappearance of the zone of separation; and the former sequestrum was then united to the living bone by blood vessels entering the

Fig. 27 (Case 2).—Roentgenogram taken, Feb. 7, 1920; operation, Dec. 9, 1919; anterior surface of the cortex of the tibia removed; drainage tube in popliteal space shown.

haversian canals. The process was similar to that found in any bone transplant, gradual absorption and deposition of new bone occurring throughout the haversian canals until all the dead bone had been replaced.

I have emphasized these facts because I believe they have a definite influence on human surgery. I shall show in the study of clinical cases that in children bone tissues that are apparently dead can be saved to advantage.

Since the introduction of the Carrel-Dakin technic, we have had results on Dr. Pool's service at the New York Hospital which correspond to a certain degree with results found in our experimental work. The following two cases show marked regeneration of bone which on either roentgen-ray or gross examination appeared necrotic.

Fig. 28 (Case 2).—Roentgenogram taken, April 10, 1920; new bone proliferation about and incorporating former dead shaft.

On account of limited time, brief summaries of only two illustrative cases will be given.

REPORT OF CASES

CASE 1 (Figs. 23, 24 and 25).—A girl, aged 5 years, came into the hospital with an acute osteomyelitis involving the upper third of the tibia. Drainage was established by removing the anterior part of the cortex in the upper

third. Later, the roentgen ray revealed a marked rarefaction and apparent sequestrum formation in the lower third. As the temperature was approaching normal, and her condition was quite satisfactory, it was considered advisable to delay operation on the lower third. Later the roentgen ray revealed subperiosteal bone proliferation around this zone of separation, and a roentgenogram one year later revealed a relatively normal appearing shaft. At the present time, she is well, without any sinus, and apparently the process is cured.

Fig. 29 (Case 2).—Roentgenogram taken, Oct. 18, 1920; new bone formation; wound healed; patient walking on leg; feels well.

Comment.—Primary roentgenographic studies of this patient disclosed the appearance of rarefaction and sequestration in the lower third of the tibia. This completely disappeared without any operative interference.

CASE 2 (Figs. 26 to 29).—A boy, aged 7 years, in whom the tibia had been insufficiently drained, elsewhere, for an acute osteomyelitis, came into the hospital extremely ill, with a temperature of 106 F., marked leukocytosis and

prostration. At the primary operation, the entire anterior portion of the cortex of the tibia was removed. There was a fracture of the upper third due to the complete destruction of the bone. Periosteum was separated by pus from the greater part of the shaft. In this case Carrel tubes were inserted posteriorly between the necrotic shaft and the periosteum. The shaft appeared dead. It was not removed because it was thought advisable to maintain this portion of the shaft to prevent deformity. After about five weeks, granulations were seen springing up on the surface of the formerly necrotic shaft. Roentgenograms taken two months after the primary operation showed new bone formation about, and apparently incorporating, the remnant of the old necrotic shaft. At the present time, the patient has no sinus and the roentgen ray revealed marked new bone proliferation without the sign of any sequestrum.

Comment.—This patient, who was too sick to stand any operative procedure, had a dead shaft exposed in the wound. After Dakinization, granulation tissue appeared on the former necrotic surface. The bone was later incorporated and the new bone formed about it. Whether or not in this case the sequestrum was sterilized by the Dakin solution, it is difficult to state; but it appears that it acted very much as did the chemical sequestrum produced by croton oil injections in the experimental laboratory.

CONCLUSIONS

From the experience obtained with these cases and from the many animal experiments, I am convinced that, in the future in the treatment of children, we can be more conservative.

First, adequate drainage should be obtained with as little trauma as possible. Second, in cases in which the patient is clinically progressing favorably, bone, which by roentgen-ray or gross examination, appears dead, may frequently be saved to advantage in order to prevent deformity and hasten convalescence.

Finally, I believe that in the past we have made bone repair appear much too complex. We have been lost in the by-ways of periosteum, endosteum and bone reticulum. It is much simpler to believe that bone occurs as a chemical deposition in connective tissue. Such a theory allows for bone formation as it appears in all parts of the body.

In bone transplants, we must assume that the transplant per se does not live but that it acts as a framework for new bone and stimulates osteogenesis. We must, therefore, apply grafts that can easily have a blood supply established, and have sufficient free surface to stimulate bone production.

In the treatment of fractures, care must be taken to increase the blood supply. This is more important than immobilization that constricts the limb. Early motion favors union for this reason.

What we are apparently doing when a bone graft is made or when extraskeletal bone occurs in an experiment is producing the right chemical state. Then the process of bone formation inevitably follows.

Until the physical chemist tells us more of the intricacies of the chemistry of the tissues, the practical surgeon should study the circumstances of bone production, that is, what factors promote its formation. He should not let the disputes of the various experimenters over terms, or the question as to whether this or that tissue produces bone, confuse the issue. The issue requires that the patients be cured, following injury or infection of the bony structures.

100 East Sixty-Sixth Street.

LIPPING FRACTURE OF LOWER ARTICULAR END OF TIBIA

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Lipping fractures of the tibia merit consideration as a separate entity because of the difficulty of maintaining reduction and the high degree of disability accompanying union in malposition.

There are two types of these fractures, the anterior and the posterior. There may be an accompanying fracture of the internal malleolus or lower end of the fibula or both, with displacement of the astragalus and foot forward or backward. In the young, there may be a separation of the epiphysis, with lipping fracture of the diaphysis.

CAUSES

The anterior fracture is caused by a sudden violent overflexion of the foot. This might occur when the weight of the body is unexpectedly thrown on the ball of the foot, as, when in stepping up onto a curb or stair, the foot slips off and is forced upward. The astragalus is forced forward and upward. Its convex anterior articulation meets resistance against the concave anterior lip of the lower articular end of the tibia. An oblique fracture may result, displacing the anterior lip of the tibia forward and upward. The concave socket which has helped to hold the astragalus in position is then broken and this fragment, together with the foot, slides forward from under the end of the tibia. The convex posterior facet of the astragalus lies against the fractured front of the tibia.

Fracture of the posterior lip is caused by catching the heel, often on a door-sill or edge of a step or curb. The ball of the foot is without support and the foot is hyperextended. The weight of the body is thrown on the foot and tends to increase this hyperextension. The posterior lip of the tibial articulation is forced against the posterior aspect of the astragalus and a fracture, from below upward and obliquely backward, results. The posterior lip of the tibial articulation goes backward and upward, and with it the astragalus and foot. The tibial fragment may be small or large. It may be a mere tearing away of the rim, to which the joint capsule is attached, or it may involve the articular surface of the tibia to the apex of its concavity. The anterior side of the astragalus rests against the posterior fractured surface of the tibia. The joint capsule may be ruptured and the tibio-astragalar ligament torn. Frequently, the periosteum is stripped up for some distance on the back of the tibia and is attached to the small fragment.

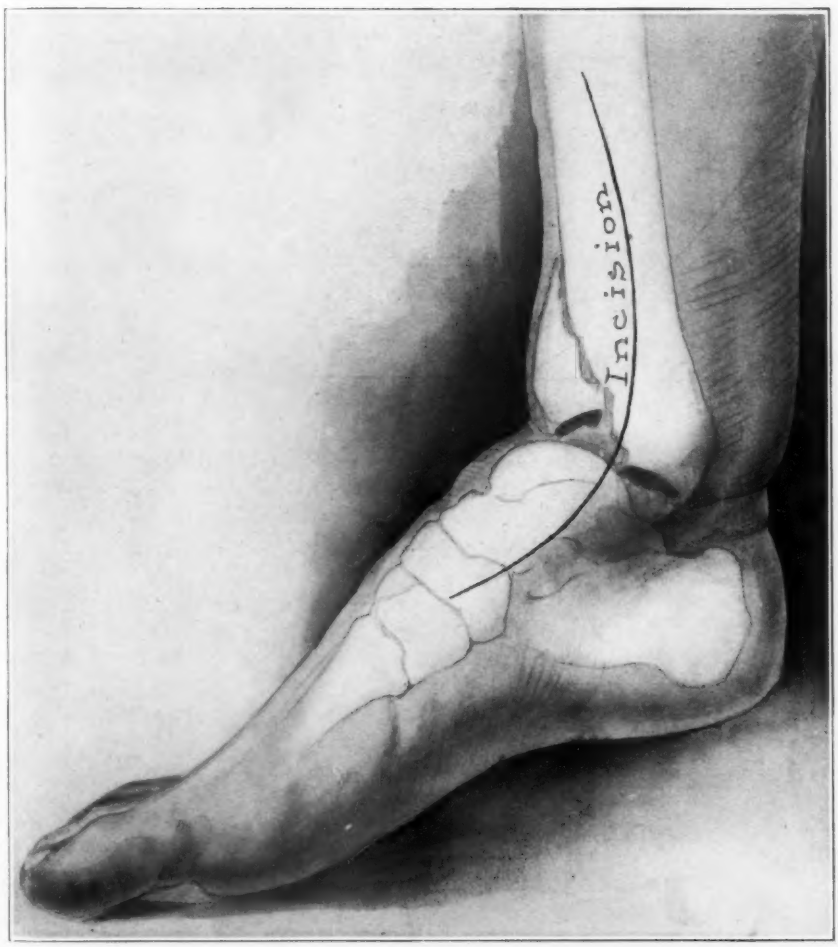

Fig. 1.—Deformity and skin incision in fracture of the anterior lip.

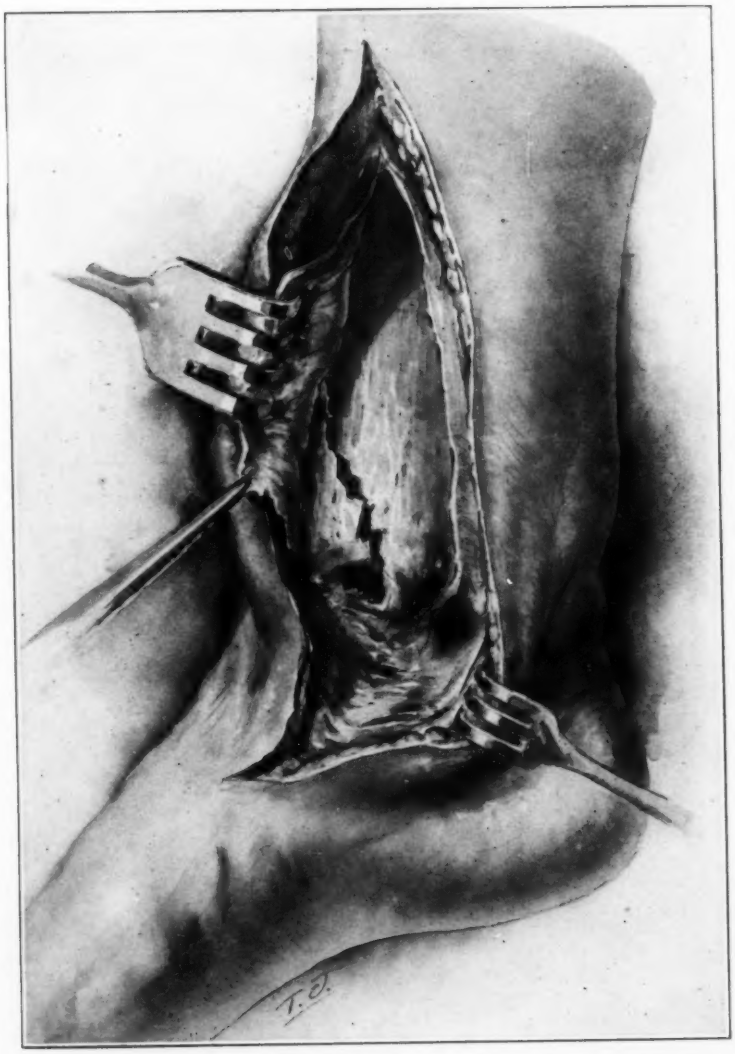

Fig. 2.—Periosteum opened, showing forwardly displaced fragment.

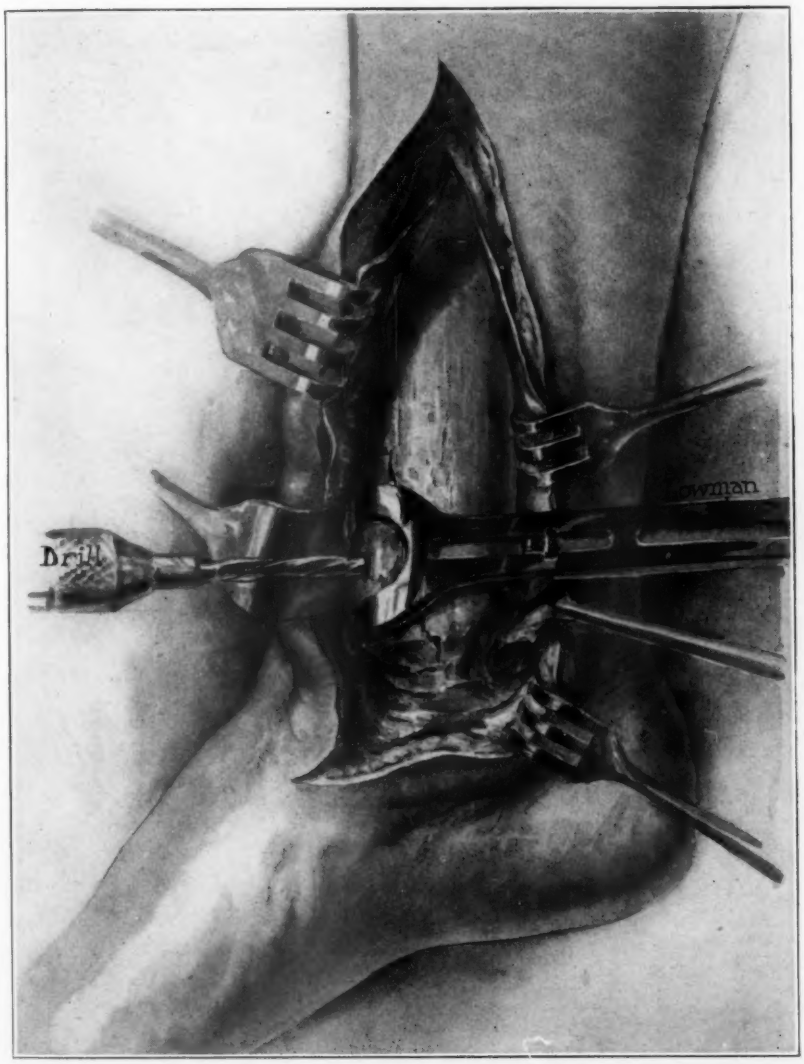

Fig. 3.—Fragment replaced and held with bone clamp while drill hole is being made.

Fig. 4.—Bed from which bone peg is cut and fragments held by bone peg.

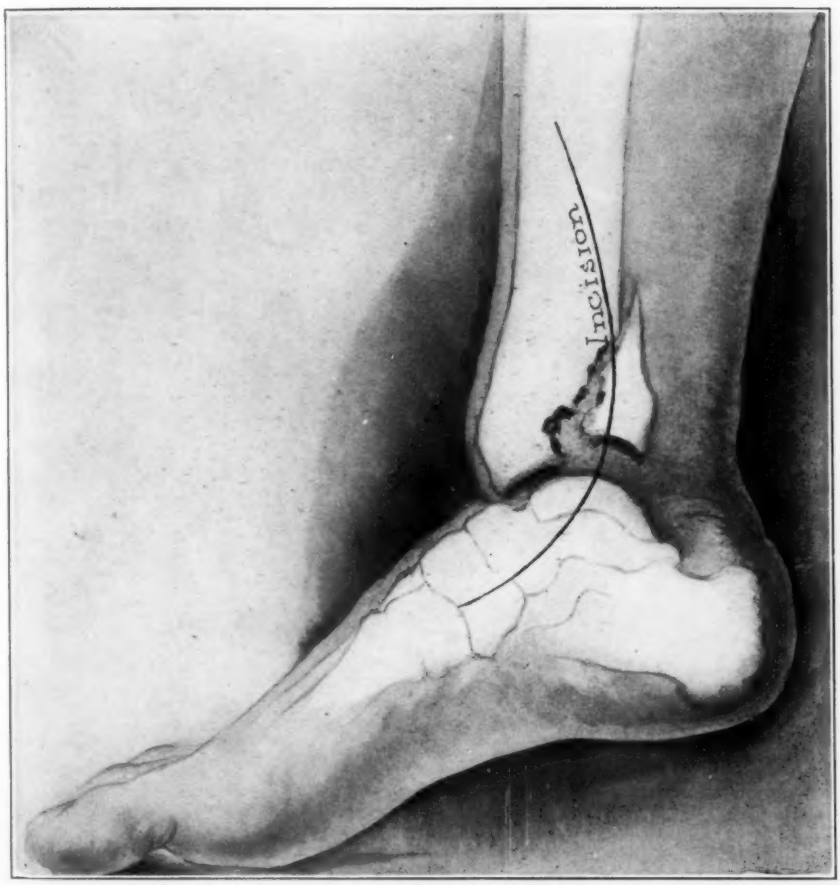

Fig. 5.—Posterior fracture of the tibia and displacement backward of the astragalus and foot, showing line of incision.

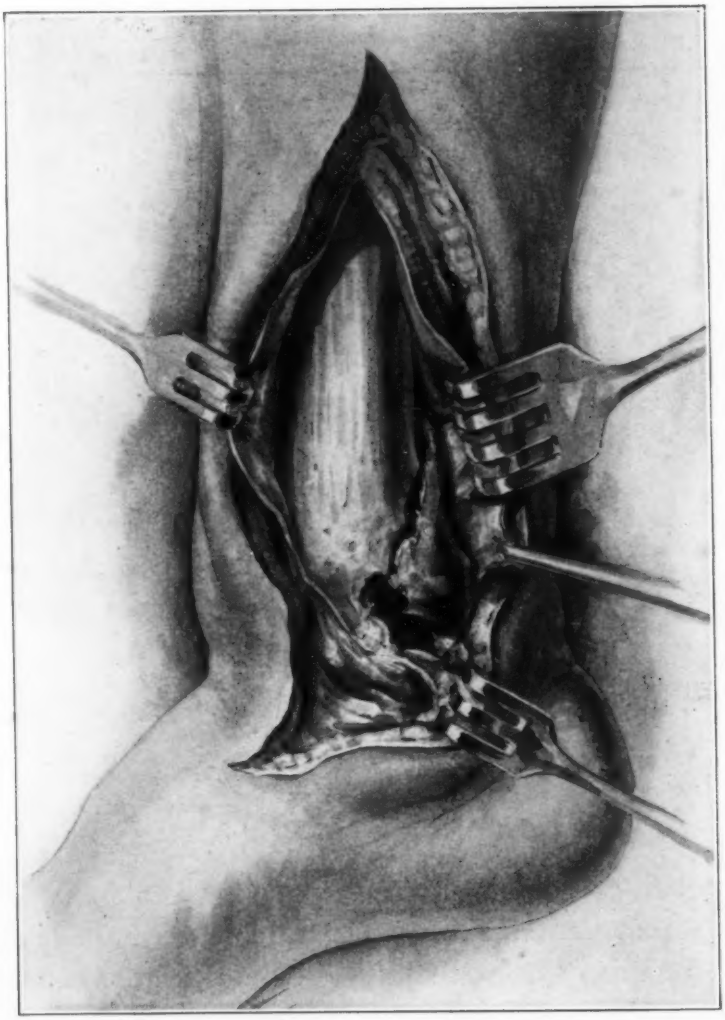

Fig. 6.—Periosteum opened, showing displaced posterior fragment.

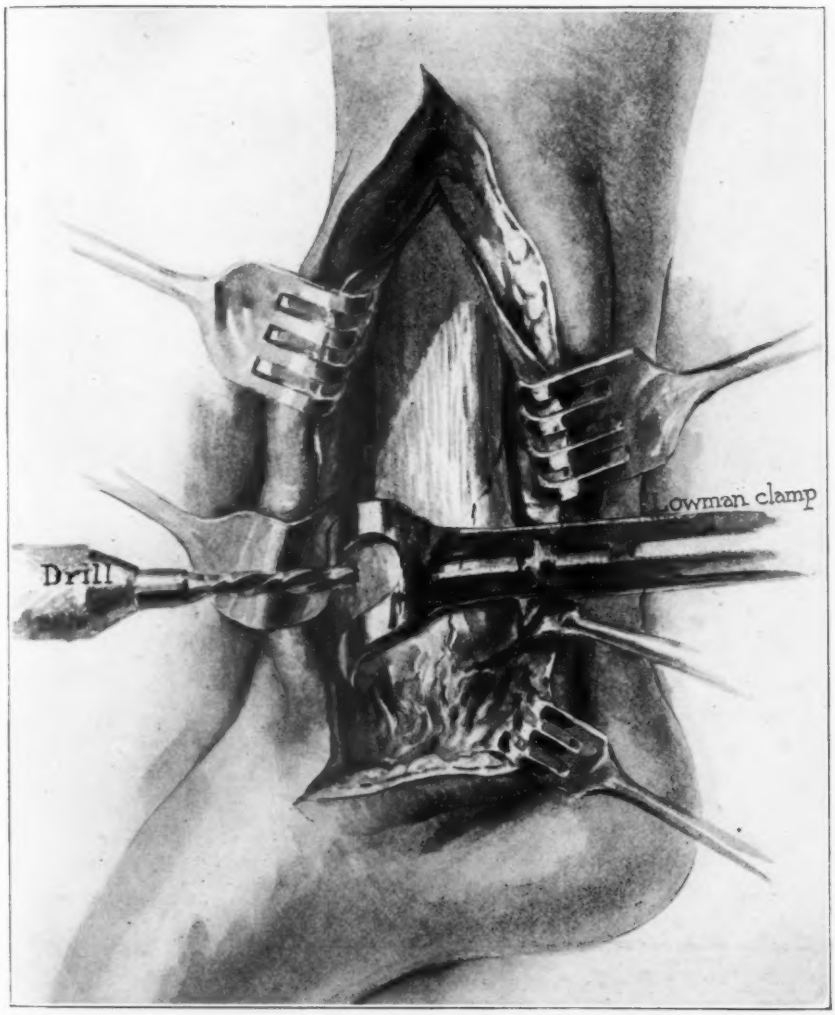

Fig. 7.—Fragment replaced and held by bone clamp while drill hole is being made, and bed from which peg has been removed.

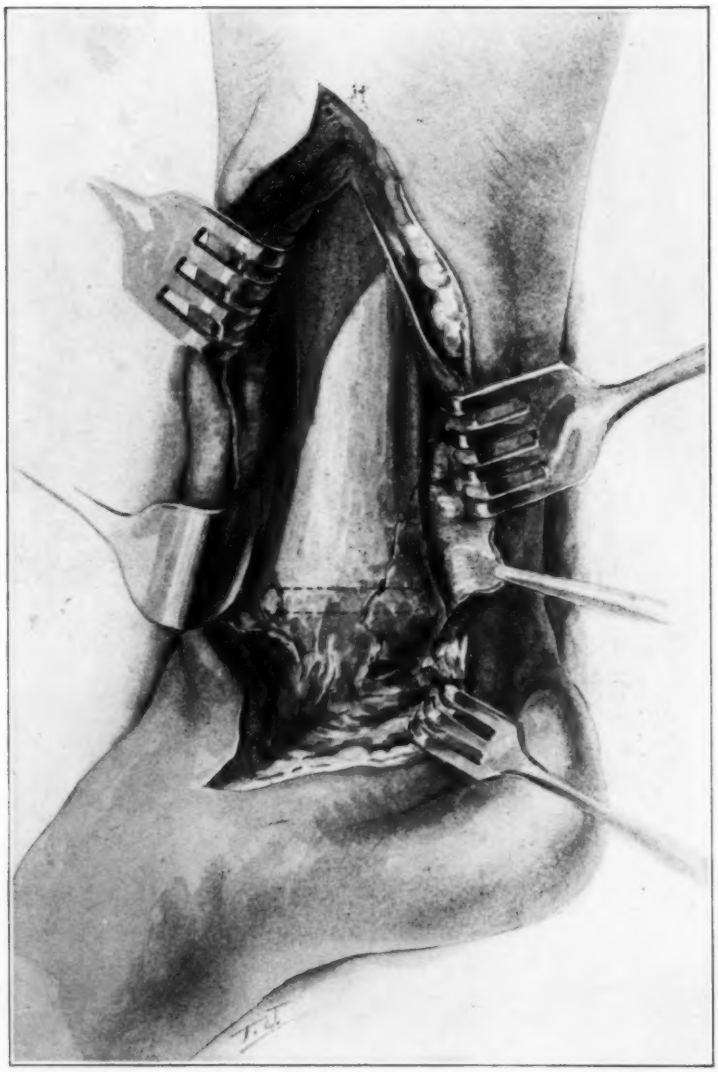

Fig. 8.—Posterior fragment held to the anterior fragment by bone peg.

The internal malleolus may be fractured and displaced medially and upward. This may complicate either the anterior or posterior type.

The nearer the line of fracture is to the apex of the concavity of the tibial articulation, the easier it will be to reduce the astragalus and the more difficult it will be to maintain it after reduction. Frequently, the surgeon has made an excellent reduction of such a fracture and applied

Fig. 9.—Fracture of posterior lip of the tibia complicated by fracture of the lower end of the fibula, fourteen weeks after injury. Foot and astragalus displaced backward and held in malposition by firm callus.

a cast to maintain it. When checking the result with a roentgenogram, he has been disappointed to find that displacement has recurred within the cast; and in spite of repeated efforts of nonoperative methods, he has been unable to hold the fragments in their normal position. Under these circumstances, an open reduction and fixation of the fragments is the only method that will be effective.

TECHNIC

Because of the complex anatomy of the ankle, open reduction of this fracture has always been difficult, especially in old cases. To simplify the operative procedures, we have developed the technic illustrated in the accompanying sketches. An incision over the medial surface of the tibia, from a point 6 inches (15 cm.) above the internal malleolus, is carried down over the malleolus and curved slightly forward to the distal end of the astragalus. The incision extends down through the periosteum to the end of the tibia. The periosteum is

Fig. 10.—Same leg as that shown in Figure 9 after cutting callus and reducing fracture and dislocation, and maintaining reduction by autogenous bone peg cut from tibia by authors' method.

reflected back from the medial surface, over the crest and over the dorsal aspect. This lays bare the fracture field in either an anterior or posterior displacement. Some shreds of periosteum or ligament may be found between the fragments. These are removed and the small fragment easily pushed into position. It is held to the large fragment by a Lowman clamp. In an anterior displacement a hole is

drilled through the small fragment into the large one, while the clamp holds them firmly. With a chisel, a peg is cut from the exposed crest of the tibia. The peg may be sharpened with ordinary bone cutters or chisel, and is then driven through the small fragment into the large one. In the posterior dislocation, the drill hole extends through the large fragment into the small one, because of easier access, and the peg, also driven from in front, passes through the large fragment into the

Fig. 11.—Separation of the epiphysis and lipping fracture of the diaphysis.

small one. The peg is cut flush with the bone and the periosteum sutured. The skin is sutured with catgut and a cast applied. The cast should run to the knee and hold the foot at a right angle to the tibia. In from six to eight weeks, the cast can usually be removed and hydrotherapy and massage instituted.

In old cases in which union has taken place in malposition, the problem is more difficult and necessitates the cutting of callus. Fre-

quently, the lower end of the fibula has been fractured and displaced backward or forward with the astragalus. Under these circumstances, it is necessary to cut the fibula in order to get the astragalus into its normal position. With the lip of the tibia securely pegged, it is not necessary to fix the fibular fragment, the cast answering the purpose fully.

Fig. 12.—Same leg as that shown in Figure 11 after reduction and pegging with autogenous bone.

ADVANTAGES OF OPERATION

This operation has two distinct advantages: First, by keeping within the periosteum, the tendons may be retracted with their sheaths and the vessels displaced without fear of hemorrhage; second, the autogenous bone peg is easily secured within the field of operation by a few chisel strokes. This makes a firm fixation material with the least likelihood of unfavorable bone reaction.

OSTEO-ARTHRITIC PROTRUSION OF THE ACETABULUM (INTRAPELVIC PFANNENVORWÖLBUNG)

ARTHUR E. HERTZLER, M.D.

HALSTEAD, KAN.

Under this head, an affection of the hip joint has been described which is characterized, anatomically, by a deepening of the acetabular cavity, due to a displacement, medially, of its inner wall, and, clinically, by pain and limitation of abduction and sometimes of adduction and of rotation. It was first described by Otto.[1] It is a rare condition. Valentin and Müller[2] were able to collect only thirty-one cases, to which they added three of their own.

This condition, as described in the literature, is due to a variety of causes. I am able to present fairly well marked examples of most of the varieties.

CASE 1.—*History.*—A man, aged 29, complained of pain in both hip joints, which he first noticed ten years previously. It began without known cause or antecedent disease except joint pains in bad weather. At first these pains involved the hands and elbows and later the knees. These joints had not bothered him in recent years. There was at no time any febrile reaction. He had not had tonsillitis; but he had had many decayed teeth, requiring extensive dental work. At the time of examination, however, there was no defect. His general health was good.

The pain in the hips began first about six years previously. It was dull in character and was located deep in the hips. It did not radiate and was never sharp. These pains were more marked in cold, rainy weather. The same kind of pain was present at this time, but the tendency to be worse under certain weather conditions was less marked now than it had been for several years. The pain was most pronounced when he first began to walk after sitting for a time, but lessened with exercise, only to increase again if the exercise was prolonged. This had recently become so marked that he had become incapacitated for all work on the farm. After exercising for a time, the muscles about the hips seemed to become stiff, making movements slow and difficult. He had noticed, a number of years previously, that it was no longer possible for him to ride horseback.

Examination.—The physical examination revealed an apparently vigorous young man. The head and trunk showed no deviation from the normal. The musculature about the hips seemed flabby and slightly atrophic compared with the general appearance of vigor of the upper part of the body. The examination of the legs revealed a degree of flabbiness when compared with the arms.

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1. Otto: Pfannenbeckenmiszstaltung infolge deformierender Osteoarthritis. Seltene Beobachtungen zur Anatomie, Physiologie und Pathologie gehörig, Ed. 2, Berlin 1824.

2. Valentin, B., and Müller, H.: Intrapelvine Pfannenvorwölbung (Pelvis Otto-Chrobak), Arch. f. klin. Chir. **117**:523, 1921.

Both trochanters projected a finger's breadth or more about the Nèlaton line. External rotation was distinctly limited, as was also internal rotation to a lesser degree. Abduction was possible only to a very limited extent, not more than 20 degrees, and the attempt to force it caused pain. Adduction was somewhat limited but less so than abduction. Flexion was possible to a right

Fig. 1 (Case 1).—Right hip, showing normal angle of the neck and shaft. The great trochanter lies less than a centimeter from the acetabular brim. The floor of the acetabulum protrudes into the pelvis. The joint surfaces are unaffected and the bone forming the floor of the acetabulum is not changed nor thickened. There is slight lipping of the lower border of the acetabulum.

angle. Within these ranges, the movement was free and painless and without any sensation of friction.

The roentgen ray demonstrated the great trochanters closer to the acetabular rim than normal (Figs. 1 and 2). The acetabulum was free from lipping

or other evidence of disease except at the lower border. The angle of the neck of the femur with the shaft was apparently approximately normal. The striking feature noted in the roentgenogram was that the acetabulum protruded toward the pelvic cavity, deepening it to a marked degree. The acetabular floor was not thickened and the surface it presented toward the pelvic

Fig. 2 (Case 1).—Left hip of the same patient.

cavity was smooth in outline. There was no evidence of disease of the femur nor of the pelvic bones. On rectal examination, the protrusion was more striking than it appeared in the roentgenogram. The sensation was as though half a billiard ball had been cemented over each acetabular region.

Diagnosis.—The slight limitation of external rotation and the marked limitation of abduction at once suggested coxa vara; but the lack of marked limitation of internal rotation made this diagnosis doubtful. The roentgen ray

showed no marked change of the angle of the neck of the femur, but did show a deepening of the acetabulum. The lipping of the lower border of the acetabulum suggested an inflammatory process.

CASE 2.—*History.*—A woman, aged 44, complained of pain in the left thigh and hip. She had been a strong and healthy child until the age of 6, when she sustained a slight injury of the left hip. She was confined to bed with continuous pain and fever. A sinus formed, but in six months she was able to get about on crutches. The sinus did not heal for nearly eight years.

She had been able to walk with crutches until six months previously, when she injured her hip slightly. She walked about for a week following the injury, but had not attempted to do so since.

Examination.—There was marked limitation of motion in all directions. Abduction was altogether impossible, as was external rotation. The roentgen

Fig. 3.—The entire lateral border is displaced markedly medially, protruding into the pelvis more than a third of its diameter. There is thickening of the bone which forms the floor of the acetabulum. The head of the femur is deformed and the neck and shaft of the femur are atrophied and rarefied.

ray revealed the whole acetabular cavity displaced markedly medially (Fig. 3). The acetabulum was deepened and there were marked changes in the acetabular border and in the neck and head of the femur. In fact, the roentgen ray would indicate a bony ankylosis, an impression heightened by the marked atrophic changes in the femoral shaft and head.

Diagnosis.—The marked median displacement of the entire acetabular cavity constituted the sole reason for including this case in this category. Esau[3] reports a case of this type. The clinical findings do not correspond to the true Otto type, so they will be referred to again later.

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3. Esau, P.: Akute Osteomyelitis des rechten Schambeins und zentrale pathologische Luxation des Oberschenkels., Deutsch. Ztschr. f. Chir. **91**:611, 1908.

CASE 3.—*History.*—A woman, aged 36, came for examination to determine whether an old hip disease would make childbirth hazardous. When 5 years old, she began to have pain in the left hip and knee. She was treated for several years with a hip splint. The pain ceased, but there was limitation of

Fig. 4.—Old tuberculous disease of the hip. There are marked trophic changes in the head and shaft of the femur. The acetabular protrusion is due to a thickening of the bone rather than an actual protrusion.

motion in the hip joint. She was given an anesthetic and the joint was freely mobilized. Following this, she had fever and swelling about the joint for several months, and when this subsided, she was unable to move the thigh at all.

Examination.—There was complete fixation at the hip joint (Fig. 4). The thigh and hip regions showed marked muscular atrophy. The roentgen ray

revealed complete ankylosis. The acetabulum was deepened and protruded into the pelvis. This protrusion was more impressive when examined by the vagina and rectum than it appeared in the roentgenogram.

Diagnosis.—The roentgen-ray findings did not correspond to those usually found in old tuberculous hip disease. However, this apparently is accounted for

Fig. 5.—Extensive carcinomatous metastasis of the ischium. The floor of the acetabulum shows thickening and some displacement.

by the marked inflammatory reaction following the manipulation under ether at a time when the original disease was in abeyance.

CASE 4.—A woman, aged 46, was brought to the hospital because of pain in the back. The details of the history and findings in this patient are of no interest here. She had had one breast removed by a caustic paste two years before, followed a year and a half later by pain in the back. The roentgen

ray revealed many metastatic nodules. It is of interest to note that the metastases in the ischium had permitted a protrusion toward the median line (Fig. 5). The picture is shown here because a similar condition was presented by Thomsen[4] as a type of osteo-arthritic protrusion of the acetabulum.

COMMENT

Case 1, here presented, seems to belong to a condition wherein the disability is due to the deepening of the acetabular socket, as already noted. It was first described by Otto.[1] As indicated by the title of Otto's paper he considered an inflammatory reaction the causative factor. In several of the cases reported, mild inflammatory reactions have preceded the deformity. Thus Wolfsohn and Brandenstein[5] report a case in a man, aged 36, who had a rather typical inflammatory rheumatism five years before. Gradually the movements in the hip joint became limited and a protrusion of the acetabular cavity followed. Schertlin[6] and Henschen[7] report similar instances. It is to this type that my Case 1 belongs. Most cases recorded apparently follow a coxitis of a relatively mild degree. The general term juvenile osteo-arthritis seems, as suggested by Wolfsohn and Brandenstein,[5] to be descriptive, except that in the majority of cases recorded the dominant symptoms appeared too late in life to be "juvenile;" it is possible, however, that the first changes began during adolescence.

Eppinger[8] believes the disturbance is due to a late ossification of the bones making up the acetabular floor. According to him, the constant muscle pressure on the cartilaginous floor is sufficient to produce the condition. Other authors combat this hypothesis chiefly for the reason that a delay in ossification has not been proved, and that the cases reported give histories of a preexisting arthritis.

The significance of frank infections of the joint, particularly by pus organisms, has been emphasized by Esau.[3] My Case 2 belongs here. In this case, a pyogenic infection may fairly be assumed. Apparently, a disturbance of the ossification centers followed, with displacement of the horizontal ramus of the pubes. I observed a patient some years ago in whom there was frank suppuration on the right side which was

4. Thomsen: Krebsige Osteomalacie, Arch. f. klin. Chir. **13**:235, 1872.

5. Wolfsohn and Brandenstein: Ueber Osteoarthritis coxae juvenilis duplex, Arch. f. klin. Chir. **96**:656, 1911.

6. Schertlin: Ueber einen Fall von intrapelviner Vorwölbung und zentraler Wanderung der Hüftpfanne, Beitr. z. klin. Chir. **71**:406, 1910.

7. Henschen: Die intrapelvine Vorwölbung und die ventrale Wanderung der Hüftpfanne, Beitr. z. klin. Chir. **65**:599, 1909; Die traumatische (spontane) Luxatio centralis femoris, Beitr. z. klin. Chir. **62**:294, 1909; Die zentrale oder intrapelvine Pfannenwanderung der Hüfte auf coxitisch-arthropathischer Grundlage, Ztschr. f. orthop. Chir. **33**:438, 1913.

8. Eppinger: Pelvis-Chrobak: Coxarthrolisthesis-Becken, Beitr. z. Geburtsh. u. Gynäk. **2**:176, 1903.

drained after several weeks. The left side became affected and was drained early. On this side, there is some acetabular protrusion with some changes in the bones. On the right side, the bone changes are extensive (Fig. 6). It is possible that the left side in this case stands midway between the extreme suppuration as shown in the right side

Fig. 6.—At the left of the roentgenogram the head of the femur and the acetabulum show extensive changes. On the right, the femur shows extensive changes; the floor of the acetabulum shows relatively slight changes but protrudes somewhat into the pelvis.

and the type Otto has shown in Figure 1. In another case, with double suppurative arthritis, there was a protrusion of the whole lateral pelvic arches (Fig. 7), being a lesser presentation of the condition shown in Figure 2. In the paper of Valentin and Müller,[2] they seem to include such cases as of the true Otto type. The gonococcus has been accused by Henschen [7] and Chiari [9] to be the cause.

---

9. Chiari: Ueber die Aetiologie und Pathogenese der intrapelvinen Pfannenprotrusion, Beitr. z. klin. Chir. **102**, 1916.

Tuberculous infection has been observed, notably by Chiari and by Bier. My Case 3 belongs to this group. The deformity here is not great, but it indicates the process by which the deformity develops. Trendelenburg [10] described one due to the echinococcus.

Tabes was diagnosed by Féré,[11] Wrede [12] and Kienböck.[13] In such instances, it appears to be a generalized overproduction, rather than the medial displacement of the floor of the acetabulum.

Fig. 7.—Double suppurative arthritis in a girl, aged 10 years. These joints were both drained. The transverse diameter of the pelvis is lessened and there is some protrusion of the acetabulum. These resemble, in a mild degree, the conditions shown in Figure 3.

Displacement from invasion by tumor was first observed by Thomsen,[4] and this also was the causative factor noted in one of the

10. Trendelenburg: Echinococcus multilocularis der rechten Beckenhälfte, Verhandl. d. deutsch. Gesellsch. f. Chir. **10**:61, 1881.

11. Féré: Description de quelques pieces relatives aux lésions osseuses et articulaires des ataxiques conservées au musée anatomo-pathologique de la Salpêtrière, Arch. de neurol. **4**, 1882.

12. Wrede: Demonstration eines Tabesbeckens und eines Otto-Chrobakschen Beckens, Tr. 82 Versamml. deutsch. Naturf. u. Aerzte in Königsberg, 1910.

13. Kienböck: Ueber die mit Protrusion des Pfannenbodens einhergehenden Erkrankungen des Hüftgelenks und ihre Beziehungen zur Arthritis gonorrhoica und Arthropathie bei Tabes, Fortschr. a. d. Geb. d. Röntgenstrahlen **18**:280, 1912.

cases reported by Senftleben [14] and by Valentin and Müller.[2] Numerous other instances have been recorded in which there was a displacement of the head of the femur inward. I had one such instance in sarcoma of the ischium and one in metastatic carcinoma from carcinoma of the breast. This is presented herewith as Case 4.

It seems doubtful whether deformities due to specific infections and to malignant growths should be admitted to this disease group. I would exclude cases due to acute osteomyelitis, tuberculosis, nerve disease and tumors. The course and pathology of these are so different from the typical cases of Otto's disease that confusion is caused by their inclusion. I would, therefore, include only about twenty of the reported cases and Case 1 of my own as typical instances of Otto-Chrobak disease. In this connection, it is not possible to speak convincingly of those associated with gonorrheal arthritis. Schlagenhaufer [15] records one instance in which a pure culture of gonococcus was obtained from a case running an acute course. Kienböck likewise reports a case. It may be, therefore, that in some of the cases of insidious onset the gonococcus may have played a part. One cannot, therefore, exclude this etiology from the typical Otto-Chrobak disease.

Viewing the reported cases as a whole, it seems probable that a change in structure of the bone is brought about by a chronic inflammatory process. We cannot do better, therefore, than to conclude with Otto that the disease is due to an osteo-arthritis.

The diagnosis of the typical Otto type is characterized by marked limitation of abduction and external rotation, with a lesser limitation in the other movements. Flexion in Schertlin's case was limited to a third of the usual range. In my case there was slight limitation of flexion. Usually, the greater trochanter is not displaced; but in Schertlin's case there was a displacement of 3 cm. In my case there seems to be some displacement upward, but the range was not above that of personal error.

The clinical importance of this disease, aside from the limitation of motion, is that it sometimes reduces the oblique diameter of the pelvis sufficiently to make it a hindrance to delivery. Henschen [7] and Kuliga [16] have each made a study of this phase of the subject.

CONCLUSIONS

1. Following a chronic arthritis, there may be a protrusion of the acetabular floor into the pelvic cavity.

---

14. Senftleben: Ueber Fibroide und Sarkome in chirurgisch-pathologischer Beziehung Arch. f. klin. Chir. **1**:81, 1860.

15. Schlagenhaufer, F.: Ueber Coxitis gonorrhoica und ihre Beziehung zur Protrusion des Pfannenbodens, Zentralbl. f. Gynäk. **30**:228, 1909.

16. Kuliga: Ueber Chrobaksches Becken, Zieglers Beitr. z. path. Anat. u. z. allg. Path. Festschr. f. Arnold, 1905.

2. This produces limitation of abduction and external rotation and some limitation of movement in other directions.

3. This protrusion may shorten the oblique diameter of the pelvic outlet.

4. The displacement of the acetabular floor by specific disease or tumor metastases should not be placed in the group of osteo-arthritic protrusion of the acetabulum of Otto.

RESULTS OF TREATMENT OF FRACTURED FEMURS IN CHILDREN

WITH ESPECIAL REFERENCE TO BRYANT'S OVERHEAD TRACTION *

W. H. COLE, M.D.

ST. LOUIS

This review of the cases of fractured femur encountered in the St. Louis Children's Hospital was made primarily to present the method of treatment and its results in simple fractures. In addition, an analysis of the entire group of cases of fractured femur, including pathologic fractures, has been made.

ANALYSIS OF CASES

Altogether, the reports of thirty-five cases [1] have been collected. Thirty-one of these were simple fractures, eighteen of which were treated by overhead traction.[2] Considering the ratio of ages, fracture of the femur is much more common in infancy, five of the thirty cases occurring in infants, 1 year of age or under.

Depending on the kind of fracture and the complications, six different methods of treatment have been used, viz.: (1) overhead traction; (2) plaster casts; (3) splints; (4) horizontal traction; (5) open reduction, and (6) modified Steinman pin.

The five cases treated by plaster cast represent almost exclusively those in which there was little or no displacement. By using a cast in the treatment of these cases, the patient is allowed to go home much earlier and without the danger of refracture. As stated, eighteen of the thirty-one cases were treated by overhead traction.

Table 3 reveals that practically one half of the thirty-one cases were transverse fractures. Almost all of the oblique fractures were treated by overhead traction. This method, however, was also used in transverse fractures. All of these five were overriding fractures. The three cases treated by open reduction were transverse fractures, two, however, with no more displacement than in those treated by overhead traction. All the cases treated by casts and splints represent almost exclusively those with very little or no displacement. Of the two patients treated by horizontal traction, one was 12½ years old.

---

* From the Department of Surgery, Washington University School of Medicine.

1. This series was taken from the service of Dr. Clopton of the St. Louis Children's Hospital, and the work was undertaken at his suggestion.

2. Bryant, Thomas: Practice of Surgery, London **2**:422, 1879.

TABLE 1.—Ratio of Simple to Pathologic Fractures

Simple—	No. of Cases
Infants (1 year or under)	5
Children (1 to 12 years)	26
Pathologic—	
Osteomyelitis	2
Syphilis	1
Osteitis fibrosa cystica	1
Total	35

TABLE 2.—Method of Treatment and Influence of Age on It

Method of Treatment	No. of Cases
Infants (1 year or under)—	
Overhead traction	1
Plaster cast	2
Splint	2
Total	5
Children (1 to 12 years)—	
Overhead traction	16
Plaster cast	4
Horizontal traction	2
Operative reduction	3
Modified Steinman pin	1
Total	26

TABLE 3.—Influence of Kind of Fracture on Method of Treatment

Method of Treatment	No. of Cases
Oblique Fractures—	
Overhead traction	13
Horizontal traction	1
Modified Steinman pin	1
	— 15
Transverse Fractures—	
Overhead traction	5
Plaster cast	5
Open reduction	3
Horizontal traction	1
Splint	1
	— 15
Greenstick — splint	1
Total	31

This is perhaps two or three years beyond the upper age limit when fractures may be treated safely by the overhead method. A modified Steinman pin was used in the case of one patient who sustained a compound fracture of the tibia, infected with gas bacilli, which necessitated amputation of the entire leg.

The figures in Table 4 demonstrate quite conclusively that the kind of fracture is distinctly determined by the location, or vice versa. With one possible exception, all oblique fractures were located in the middle third. Transverse fractures in the middle third, however, are quite frequent, as indicated by a ratio of six transverse to fourteen oblique fractures.

APPARATUS FOR OVERHEAD TRACTION

One of the greatest advantages of overhead traction is the simplicity of traction and the relatively slight attention required. On account

TABLE 4.—LOCATION OF FRACTURES

Kind of Fracture	No. of Cases
Upper third—	
Transverse	3
Oblique	0
Total	3
Middle third—	
Transverse	6
Oblique	14
Greenstick	1
Total	21
Lower third—	
Transverse	6
Oblique (at junction of middle and lower third)	1
Total	7

of the decreasing flaccidity of the hip joint with age, the use of overhead traction is restricted, roughly, to patients below the age of 10. A decided advantage in treating fractures in infants by this method is the cleanliness and immediate relief of discomfort that it affords. We have failed, as yet, to see a form of splint or cast which, when applied to a patient under the age of 2, could be kept free from urine and feces. Moreover, children, when put up in splints, almost invariably cry and fret for many days following the fracture. I believe we have not had a single patient who did not cease fretting within twelve hours after the application of overhead traction.

The overhead method is applicable to the average child's bed or crib, since practically all of them have head and foot railings of equal height. A bar is placed horizontally from the top rail of the head piece to the top rail of the foot piece. Ordinary adhesive strips are

used for traction, and applied well up to the site of the fracture. Reinforcing strips should be applied, preferably horizontally up the leg to the line of fracture and not by circular turns, which cause constriction followed by pain and edema. A bandage is applied snugly around the extremity, not only to keep the limb warm, but also to encourage the adhesive to stick. A heavy cord is tied to the foot piece of the adhesive strip. After lifting the extremity to a right angle with the bed, the extension cord is carried to a pulley attached to the cross-bar; from there it is carried to a pulley at the foot of the bed so that the weight hangs out of the child's reach. Coaptation

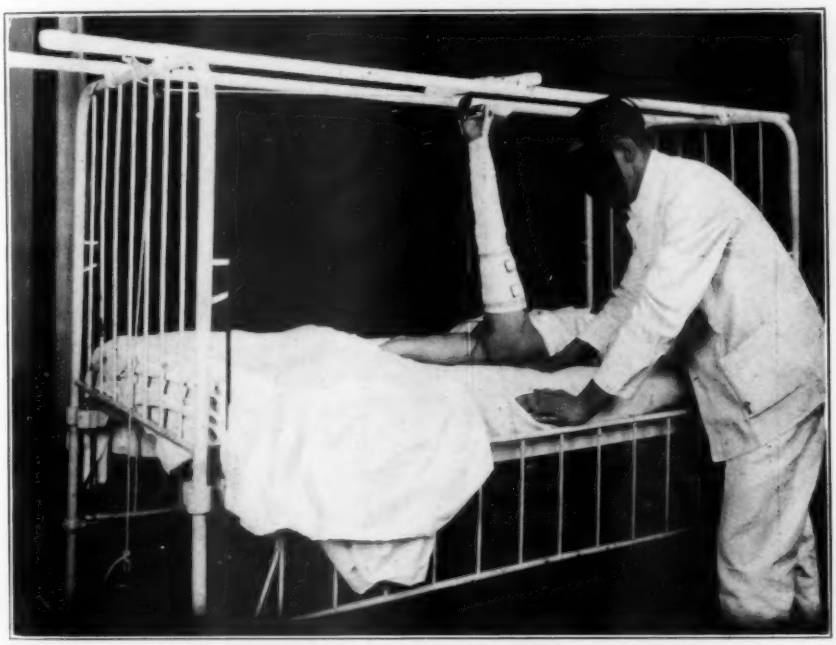

Fig. 1.—Apparatus for overhead traction; sufficient weight is used barely to lift the buttock off the bed; one horizontal bar may be used instead of two.

splints are usually applied in the beginning of the treatment because of the support given at the site of fracture if the child twists his body suddenly. The simplest splints are made by laying ordinary wooden tongue depressors on a wide adhesive strip at a distance of one-half inch (1.7 cm.), and a similar adhesive strip applied to cover them. The strips should be just wide enough to allow exposure of a half-inch of the ends of the tongue depressors. This flexible splint is wrapped once around the site of fracture after a towel or bandage has been applied. Wide linen tapes with buckles are most satisfactory for holding the splint in place.

If desired, instead of using one horizontal bar, two may be laid across the top rails of the bed at a distance of about a foot apart, and the extension pulley tied to a bar connecting the two horizontal bars (Fig. 1). This allows a slightly more flexible extension, though it is not at all necessary. Ordinarily, the limb is held in overhead traction

Figure 2

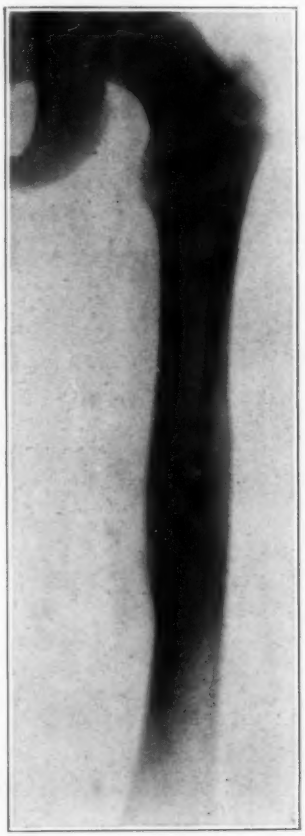

Figure 3

Fig. 2.—Oblique fracture of middle third of femur of patient, 4 years of age; roentgenogram taken at time of fracture.

Fig. 3.—Same patient as in Figure 2, one and one-half years after fracture; overhead traction used.

for from three and one-half to four weeks. At the end of this time, a plaster cast is applied, and at the end of five and one-half or six weeks, the patient is discharged. The cast need be worn only two or three weeks.

This method of treatment, or ones similar, is quite commonly used and has been practiced for thirty-five or forty years. Very few

reports concerning it, however, are found in the literature. It is mentioned by McCosh,[3] in 1897, as a practical means of treating fractures in children, but no cases are cited. Sterns [4] of Cleveland used it in infants in 1905, with very successful results. A simple modification has been suggested by Silver,[5] consisting in attaching a vertical bar

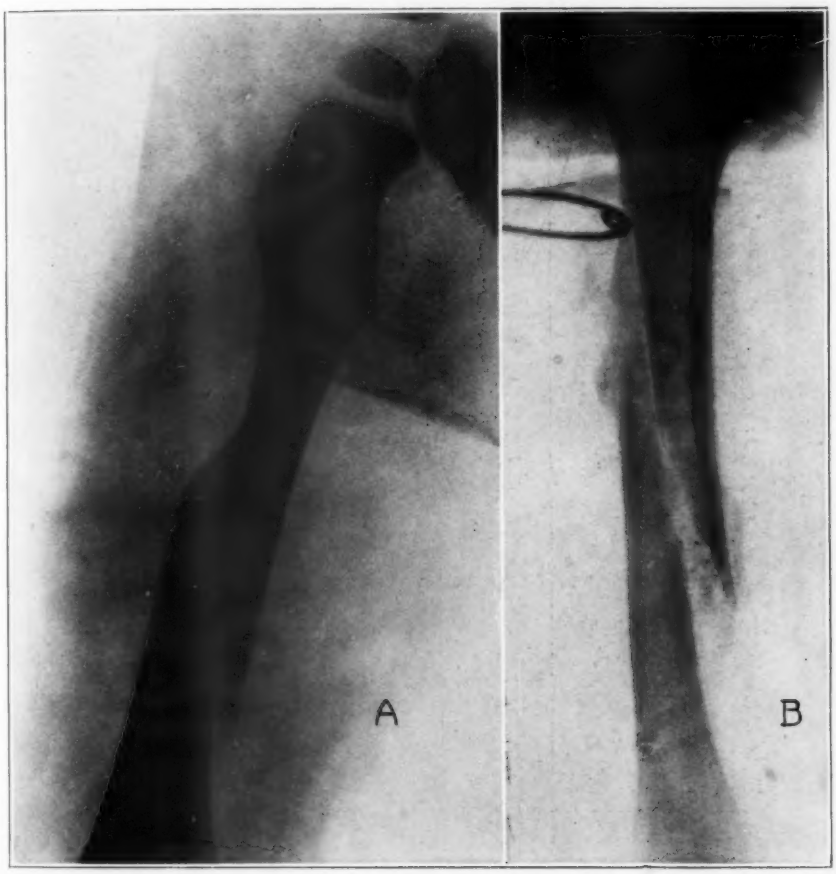

Fig. 4.—*A*, oblique fracture of middle third of femur of patient, 2 years of age; roentgenogram taken at time of fracture; *B*, appearance of femur two weeks after fracture and application of overhead traction.

to a Bradford frame. Mention of overhead traction is found in a few of the textbooks [6] on surgery, but no very extensive description

3. McCosh: Ann. Surg. **26**:368, 1897.

4. Sterns: New York M. J. **81**:992-994, 1905.

5. Silver: Ann. Surg. **49**:105-106, 1909.

6. Warbasse, J. P.: Surgical Treatment, Philadelphia, W. B. Saunders Company **1**:590, 1919. Stimson, L. A.: Fractures and Dislocations, Philadelphia, Lea & Febiger, 1910, p. 408.

of results is given. Various methods of operative reduction, such as the use of ice tongs, steel pins, plates and metal rings are employed; but certainly they are indicated in a relatively small percentage of cases. Satta,[7] of Bologne, however, has used the metal ring, similar to Parham bands, with very favorable results as secondary treatment in correction of deformity. Speed [8] has adopted a method of vertical sus-

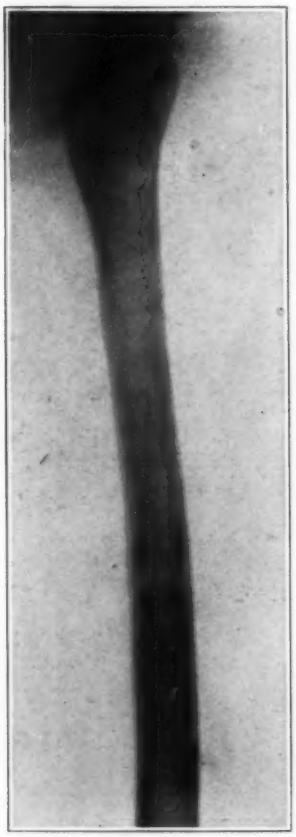

Figure 5

Figure 6

Fig. 5.—Femur of same patient as in Figure 4, four days after fracture.

Fig. 6.—Oblique fracture of middle third of femur of patient, 2 years of age; roentgenogram taken at time of fracture.

pension, obtaining practically the same traction as in the overhead method, but it is more complicated, inasmuch as a Thomas splint is used. I believe that he has been a bit unfair to himself in stating

7. Satta, F.: Chir. d. org. di movimento **4**:311-345 (July) 1920.
8. Speed, Kellogg: Surg., Gynec. & Obst. **32**:527-534 (June) 1921.

results in terms of anatomic value, because many of his patients in whose cases the results were marked poor will quite certainly return a few years hence with perfect functional, and probably perfect anatomic, results.

Close observation of the progress of healing is made by the portable roentgen-ray machine, while the extremity is in traction. However,

Figure 7

Figure 8

Fig. 7.—Same patient as in Figure 6; two and one-half years after fracture; overhead traction used.

Fig. 8.—Transverse fracture of middle third of femur of patient, 1½ years of age; roentgenogram taken at time of fracture.

within a few days, the pain of jolting is eliminated and the bed may be moved to the roentgen-ray room as often as desired, without disturbance to the child. The simplicity of the treatment affords adequate allowance for this.

ANALYSIS OF RESULTS

Although the condition of the patient when discharged from the hospital is a fair criterion of the ultimate result, accurate estimation of the physical condition cannot be made until he has been observed for at least one year. Therefore, an attempt has been made to secure the greatest number of returns possible. However, only eleven of the thirty-one patients returned for observation. We hope and rather firmly believe, however, that the reason for failure to get a more complete return lies in the fact that the results have been so satisfactory that the patients deemed an examination unnecessary. Especially is this likely, since the patient with the only unsatisfactory result was practically the first to return after receiving notification. This patient (Fig. 17) was an infant, 1 year of age, with a history of greenstick fracture of the middle third of the femur, which occurred twelve days previous to admission.

TABLE 5.—RETURN CASES

Method of Treatment and Kind of Fracture	No. of Cases
Overhead traction—	
Oblique	4
Transverse	2
Operative reduction—	
Transverse	1
Cast—	
Transverse (very little displacement)	1
Transverse (very little displacement)	1
Splint—	
Transverse (two weeks old fracture when received)	1
Greenstick (twelve days old fracture when received)	1
Total	11

It was treated by splints previous to entry to the hospital, and was treated so here because apparently only a very slight deformity existed. The deformity consisted of an anterior bowing which, it was believed, could be corrected with minor treatment. The error was seen, however, after several days' observation and operative interference was advised. The mother refused to permit operation and the child was discharged under protest. Subsequent observations (Fig. 18), two years later, revealed a marked anterior bowing of the femur, a moderate limp and one-half inch (1.7 cm.) shortening of the limb.

That operative reduction is not necessary in transverse fractures, with very few exceptions, is shown quite conclusively by Figures 9 to 14. Roentgenograms in each case revealed complete displacement, with about one-half inch overriding even after several days. Observation, fourteen months after discharge of one patient, and three years

after discharge of the other patient, revealed no deformity except a very slight bone thickening. There was no subjective evidence of fracture whatever.

The oblique fractures, all of which were treated by overhead traction, showed no subjective evidence of fracture. Roentgenograms revealed only a very slight bone thickening. In the late pictures of some of the oblique fractures, no bone change at all could be seen.

Figure 9

Figure 10

Fig. 9.—Same patient as in Figure 8; three weeks after fracture and application of overhead traction.

Fig. 10.—Lateral view of femur of same patient as in Figures 8 and 9, two years after fracture.

Figure 15 represents a transverse fracture of the upper third which was put up in a cast after attempted reduction. The failure was seen on roentgenographic examination, and operative reduction with use of Lane plates was resorted to by Dr. Fisher. Six weeks later they were

removed by him. Roentgenograms, two years later, revealed perfect alinement, with a moderate bone thickening, quite certainly more thickening than seen in any of the other cases. No shortening was found and no subjective symptoms were detected.

Perhaps one of the most striking observations is the absence of shortening seen in cases which healed with fragments distinctly in an

Figure 11

Figure 12

Fig. 11.—Anteroposterior view of femur of same patient as in Figures 8, 9 and 10, two years after fracture.

Fig. 12.—Transverse fracture of middle third of femur of patient, 2 years of age; roentgenogram taken at time of fracture.

overriding position. Moreover, when the patient returns a few years later, the affected extremity shows no shortening. Repeated roentgenograms of the knee joints a few weeks and a few years after treatment reveal no separation of the femur from the tibia due to stretching of the ligaments about the knee joint. The question arises as to the loca-

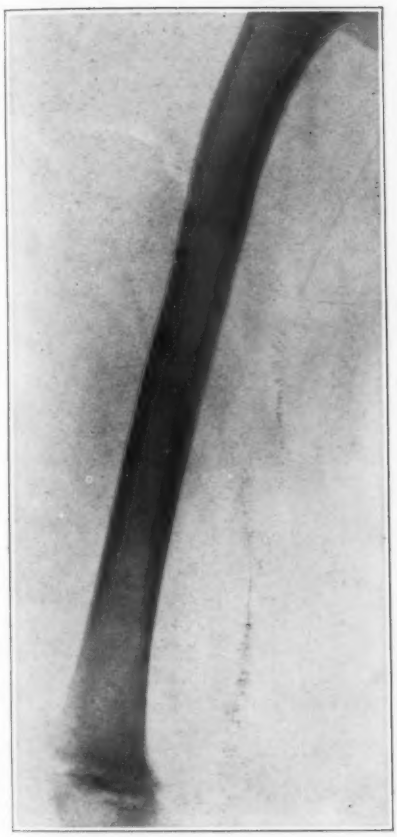

Figure 13

Figure 14

Fig. 13.—Same patient as in Figure 12, two years after fracture; overhead traction used.

Fig. 14.—Transverse fracture of upper third of femur of patient, 4 years of age; roentgenogram taken after attempted reduction and application of cast.

Figure 15

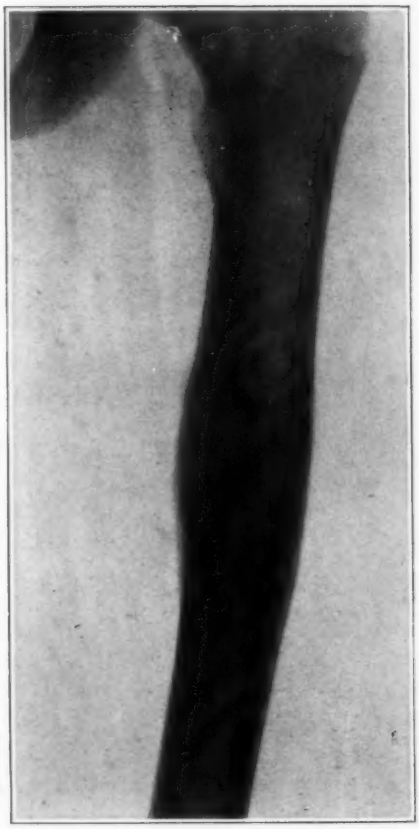

Figure 16

Fig. 15.—Same patient as in Figure 14, six weeks after application of Lane plate and six and one-half weeks after fracture.

Fig. 16.—Same patient as in Figures 14 and 15, two years after fracture, showing amount of callus remaining.

tion of the compensation. The ligaments of the ankle are not included in the traction at all. Furthermore, one cannot conceive of the hip joint allowing much room for lengthening of the extremity. Apparently, the only explanation remaining is that young bone yields to the constant pull, and thus makes up for the few centimeters necessary for compensation.

Figure 17.

Figure 18

Fig. 17.—Greenstick fracture of middle third of femur; roentgenogram taken at time of admission, two weeks after fracture; operative reduction was refused and the patient discharged under protest.

Fig. 18—Femur of same patient as in Figure 17, two years after fracture, showing marked anterior bowing deformity.

PATHOLOGIC FRACTURES

During the five years when thirty-one cases of simple fractures of the femur were received, four cases of pathologic fracture were encountered.

Two occurred in cases of osteomyelitis, one in a case of syphilis, and the last, in a case of osteitis fibrosa cystica.[9] One of the fractures occurring in an acute case of osteomyelitis was an acute case of recent onset; the other was an acute case with a history of chronicity, several months previously. The case of syphilis was complicated by a

TABLE 6.—PATHOLOGIC FRACTURES

Cause of Fractures	No. of Cases
Osteomyelitis	2
Syphilis	1
Osteitis fibrosa cystica[9]	1

poliomyelitis paralysis in the same extremity as the fracture. The child was given heavy antisyphilitic treatment and discharged wearing a brace.

CONCLUSIONS

From the foregoing data, the following conclusions may be deduced:

1. The immediate shortening due to overriding of fragments in growing bone tends to correct itself, even though the fragments have healed in overriding position.

2. Alinement of the fragments is more important than the position of the ends of the fragments.

3. Perfect functional results may be obtained from a transverse fracture, with overriding, by using overhead traction.

4. The younger the patient, the more nature compensates for malposition and surgical inefficiency.

5. Overhead traction is more applicable, and will give better results, than any other method in the treatment of fractured femurs in children.

9. This case is being reported by Dr. Sherwood Moore. Full details will be given in his report.

CORRECTION

In the September issue of the ARCHIVES appeared an article on "The Function of the Gallbladder in Biliary Flow" by Conrad Jacobson and Carl Gydesen. A footnote should have accompanied the article to the effect that the experimental work on which the article was based was done in the laboratories of the University of Minnesota Medical School, during the time that Dr. Jacobson served as Associate Professor of Surgery.

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